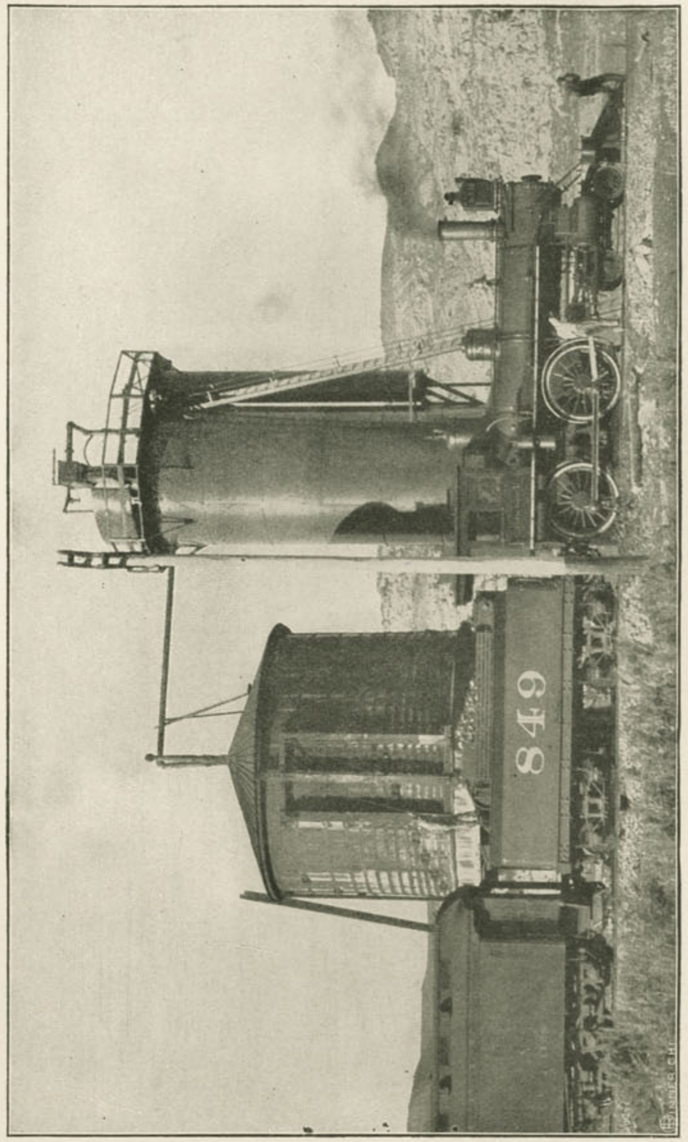

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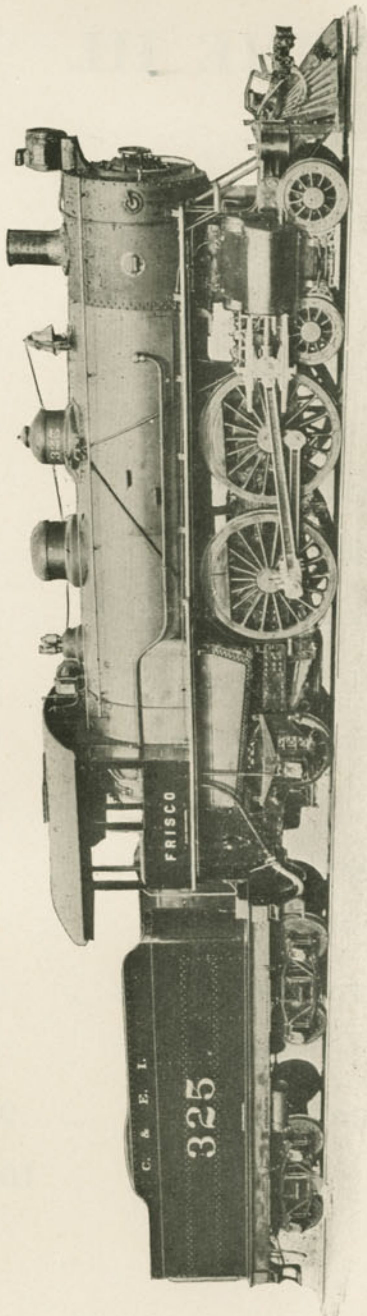


ATLANTIC TYPE LOCOMOTIVE FOR FAST PASSENGER SERVICE, CHICAGO & EASTERN ILLINOIS R. R.
(Baldwin Locomotive Works)

The Walschaert Valve Gear.

Of all the improvements that have been made on locomotives in recent years, there is one which has created more interest than any other, and that is the application and design of the Walschaert valve gear. While this gear is over sixty years old, it has not been until a few years ago that the engineers in the United States appreciated its advantages. This improved design of valve gear was patented by Egide Walschaert in 1844, and although it was never used to any extent during his lifetime, it is now considered to be almost indispensable in meeting the conditions which have recently arisen because of the developments of the high power locomotive in this country. About ninety per cent of the principal locomotives in Europe are equipped with it, and the rapidity with which it is now being applied to American locomotives indicates that in the future it will become the prevailing type in this country.

Comparison of the Walschaert and Stephenson Valve Motions. The Walschaert valve gear differs chiefly from the Stephenson link motion in that it requires for each cylinder but one eccentric, or its equivalent, to insure the movement of the valve, and by the elimination of the heavy eccentrics and their connections the axle is relieved of an appreciable portion of its dead weight. It also makes it possible to place the gear outside the driving wheels in a more accessible position, where the parts can be readily oiled, inspected and repaired.

While it may not be possible to adjust the valve as readily with the Walschaert gear as with the Stephenson motion, for the reason that the parts and connections are not as susceptible to change, it is not as liable to become disarranged, and if correctly designed and fitted up will give accurate results.

The chief point of difference between the Walschaert and

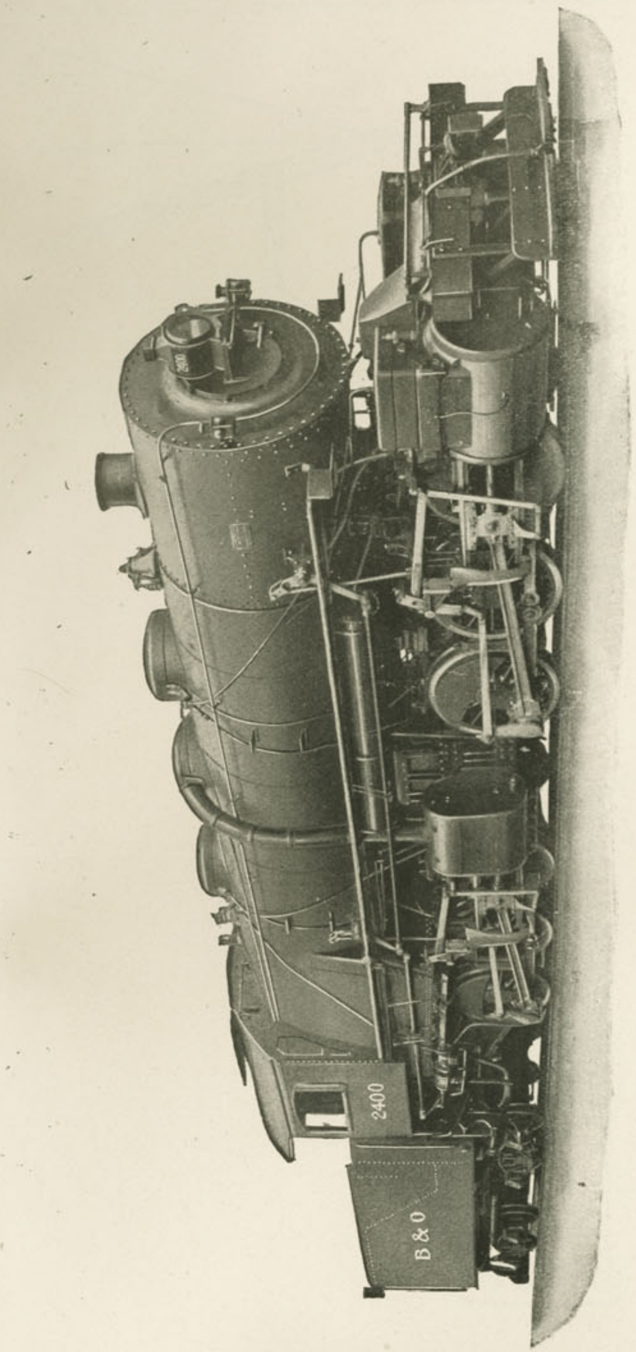
Stephenson gear when both are in proper condition is, that the former gives to the valve a constant lead at all cut-offs, whereas the latter produces an increase of lead by linking up the engine, which becomes excessive at short cut-offs. This very point has been the subject of much controversy. It has been argued that in full gear, when the speed generally is slow, only small lead is needed, but at higher speed more lead is required. This increase of lead at high speeds is accomplished by the Stephenson motion, though it admittedly becomes excessive at early cut-offs, causing considerable compression and preadmission, detrimental both to maintenance and to smooth running. In fact, the increase in lead counteracts, to some degree, the work done by the steam on the driving side of the piston, which thereby also affects the speed of the engine. The proper amount of lead, however, is dependent somewhat on the service, and the port opening becomes larger with a larger lead; or, in other words, when all other conditions are equal in a Stephenson or Walschaert gear, the port openings differ by the same amount as the lead. As the advantage of any additional port opening, by means of a larger lead, is more than offset by the increase in compression and preadmission, the larger lead would bring about at early cut-offs, and would do no good in the later cut-offs, even if it did not do any harm.

Equal cut-offs in both ends of the cylinder are more easily secured than with the Stephenson motion, and the play of the engine on its bearings has practically no influence on the steam distribution.

In the Walschaert valve gear the operating eccentric is secured to the driving axle either directly or by a return crank from one of the crank pins.

The position of this eccentric or crank is such as to give the proper valve travel, the throw corresponding with the movement of the valve irrespective of its lap and lead, the angular advance of the eccentric being 0 degrees.

Fundamental Principles. The Walschaert valve gear may be said to be based on a fundamental principle of its own. The motion of the valve is derived from two sources, namely, the main crank by connection to the crosshead, and from an eccentric placed approximately at right-angles to the main crank, as shown in Fig.



MALLET ARTICULATED COMPOUND LOCOMOTIVE—BALTIMORE & OHIO RAILROAD
(American Locomotive Company)

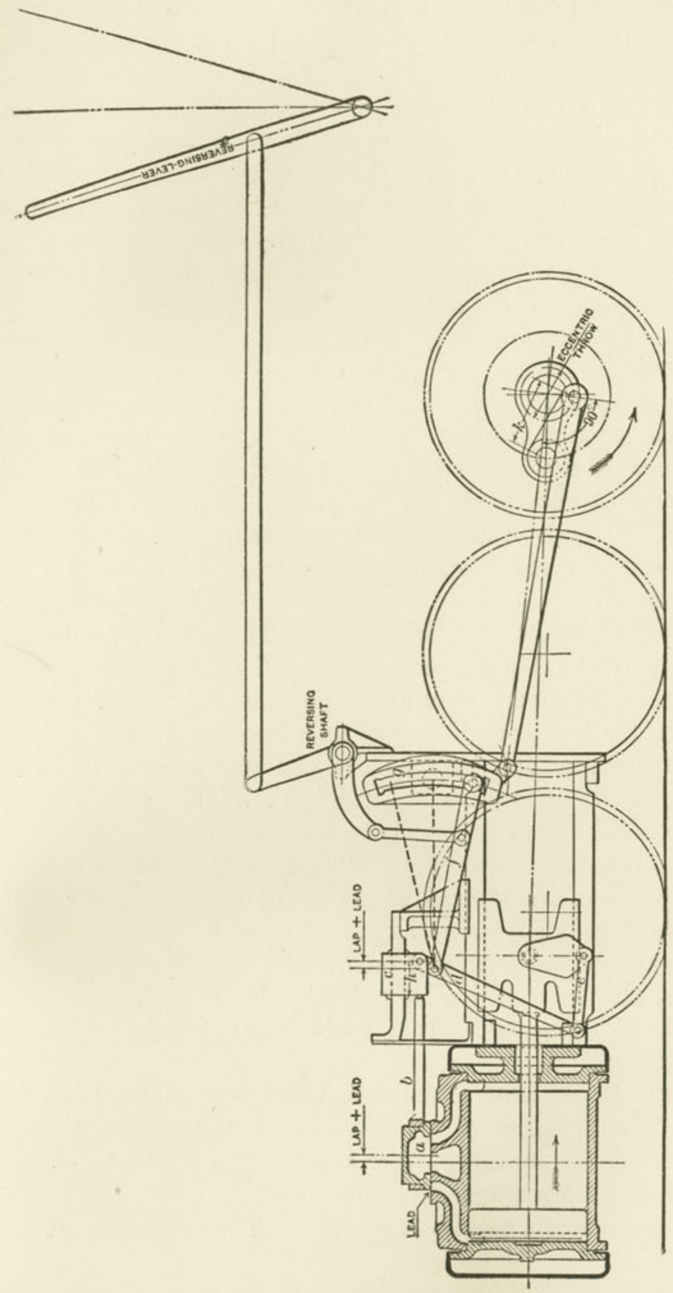


Fig. 1.

WALSCHAERT VALVE GEAR DIAGRAM.

1. The crosshead connection imparts the motion of lap and lead at the extremities of the stroke of the piston, at which moment the link is in its central position. Therefore, in the midgear, with the reverse lever in its center notch, this will be all the motion imparted to the valve, and the radius bar becomes stationary. The link is curved to a radius equal to the length of the radius bar. By moving the reverse lever forward the eccentric motion is brought into combination with the motion from the crosshead, producing a valve opening for the forward motion of the engine, and by moving the reverse lever backward the link block is brought to the opposite side of the link fulcrum, resulting in a valve opening governing the backward motion of the engine, in effect similar to that of the Stephenson motion. The action of this one eccentric is therefore the same as if it was two eccentrics, one for forward and one for backward motion, placed diametrically opposite each other, and the angle of advance in the Stephenson motion is taken care of by the main crank in the crosshead connection. The latter motion being constant, it follows that the lead remains constant at all points of cut-off.

Economy of Walschaert Valve Gear. There is no fundamental reason why the Walschaert gear should produce any greater economy in steam consumption than the Stephenson motion when both are in the best condition, but an advantage in this respect comes to the Walschaert gear by the fact that it remains in its good condition if once made so, and is therefore on an average more economical both in steam consumption and maintenance of the gear than the Stephenson gear. The accessibility for attention is a great point of undisputed advantage of the Walschaert gear, which is also highly appreciated by the enginemen and attendants. The bracing between the frames permitted by the Walschaert gear has brought about a considerable reduction in the maintenance expense by the less wear and tear this additional rigidity imparts to the entire engine.

Reasons for Applying Walschaert Valve Gear to American Locomotives. The size and arrangement of parts in a modern locomotive make it difficult for an engineer to properly examine the eccentrics and link motion when the engine is on the road, and breakdowns are more frequent on this account. The conditions of service also tend to make it more and more difficult for the enginemen to give the close inspection and care which are demanded in other branches of engineering service with high speed machines. With the Walschaert valve motion only a single eccentric or its equivalent is necessary for each valve. As usually constructed, it is found more convenient to substitute a return crank, thus reducing the pin bearings to the smallest possible diameter, so that they may be readily lubricated, and, owing to the small amount of work they have to do, give satisfactory service and absolute freedom from heating.

For large locomotives, where the driving axles are of such diameter as to greatly increase the diameter of the eccentrics, the Walschaert valve gear is particularly useful. It is also found of essential advantage on locomotives having relatively small wheels and engaged in freight service, necessitating a high relative speed.

The principal reasons for applying the Walschaert valve gear to American locomotives are, therefore, as follows:

1. **Accessibility.** For very large passenger and freight engines, it was found that there was not room enough under the engine for the Stephenson gear. The eccentrics are crowded, and proper inspection, not to speak of proper care, is difficult, except over a pit. Valve gears to be properly maintained must be accessible for inspection and lubrication. In the Walschaert gear all the parts are on the outside of the engine.

2. **Weight.** The saving in weight of the Walschaert gear over the Stephenson gear is in some cases close to one-half. Besides the dead weight saved, this means reduced momentum of the moving parts, less friction, and consequently less lubrication is necessary.

3. **Directness.** The Walschaert valve gear transmits the moving force to the valve in nearly straight lines, thus avoiding the springing and yielding of the rocker arms, rocker shafts and transmission bars, which cannot be avoided in these parts of the Stephenson motion, even if they are made very heavy.

4. **Wear.** This valve gear, not having any large eccentrics, will always remain permanently in adjustment, as all connections in the gear are made with pins and bushings which are specially designed to resist wear. Large eccentrics, as used on the Stephen-

son gear, besides occupying large space, wear unevenly and lubrication is difficult.

5. **Operation.** Considerable lost motion is always found in the Stephenson gear because the two eccentrics move through wide angles, resulting in a wedging action of the link block, which strains the gear when working hard. The Walschaert links oscillate through smaller angles, producing less lost motion.

6. **Bracing the Frame.** The removal of the valve gear from between the driving wheels facilitates bracing the frames of the locomotive laterally.

7. **Constant Lead.** The arrangement of the gear is such that the valve always gives constant lead for all cut-offs, whereas the Stephenson motion produces an increase of lead which becomes excessive at short cut-offs.

The lead of the Walschaert valve gear is constant, because it is obtained from the straight line motion of the piston, instead of from the circular motion of the axle. The combination lever has its lower end connected to the crosshead and the upper end to the valve stem where an outside admission valve is used. With the use of inside admission valves, the points of connection of the radius rod and valves are reversed, the radius rod being connected to the extreme upper end of the lever and the valve stem connected intermediately.

Advantages of Constant Lead. So far as the distribution of steam in the cylinders is concerned, the constant lead, which is a feature of this motion, is not considered objectionable, and it has some distinct advantages. Under such conditions it is possible to determine upon the amount of lead the engine should have at the most economical point of cut-off. This point determined, and so designed, it cannot be altered by anyone in the shops or roundhouses. Another advantage is that it prevents valve setters from attempting to produce results by moving the eccentrics into improper relations with each other.

The constant lead of the Walschaert motion prevents the sealing of the cylinders by the piston valve when the piston is at the end of its travel or approaching it. Whereas, with the link motion, either by derangement or excessive wear, the valve laps the ports at the end of the stroke, thus causing excessive compression and many other troubles.

Another feature of the motion which appeals to the engineer is the ease of handling the reverse lever when the locomotive is running at a high rate of speed.

Description of the Walschaert Valve Gear. The general arrangement of the Walschaert valve gear as applied to a Consolidation freight locomotive is shown in Fig. 2. The names of the different parts of the valve gear are shown in Fig. 3, which represents the outline of this type of gear as used on a Mallet Articulated compound engine. The motion of the valve is derived both from the crosshead and an eccentric crank on the driving axle. The crosshead connection imparts the lap and lead at the extremities of the stroke, when the eccentric crank is in its middle position. The eccentric crank in this position imparts its fastest movement to the valve to give a very quick opening. The crosshead motion in advancing from the dead point effects approximately the same uniformity in the combined motion as if the valve derived its motion from a single crank or eccentric set with an angle of advance corresponding to the lap and lead, and which may be illustrated graphically in the same manner as that of the Stephenson motion, the only variation due to this gear being that it gives an invariable lead.

Unlike the Stephenson link, with its independent eccentrics, it cannot be adjusted, and consequently it must be correctly designed and fitted up. The various points must be carefully laid out in order to give the best results in the combination movement of the parts of the motion. In the construction of the Walschaert gear the desired travel of the valve, the lead, and the maximum cut-off, which determines the lap of the valve, are selected. The stroke of the piston being given, the combination lever is proportioned so that a motion equal to the lap and lead is given to the valve gear when the crosshead is moved from one end of the stroke to the other. The link may be made of any approved design, and is so located that the radius bar will have a length of at least eight times the travel of the link block, and the radius of the link should be equal to the length of the radius bar.

Arrangement of the Link. The link is of any convenient form,

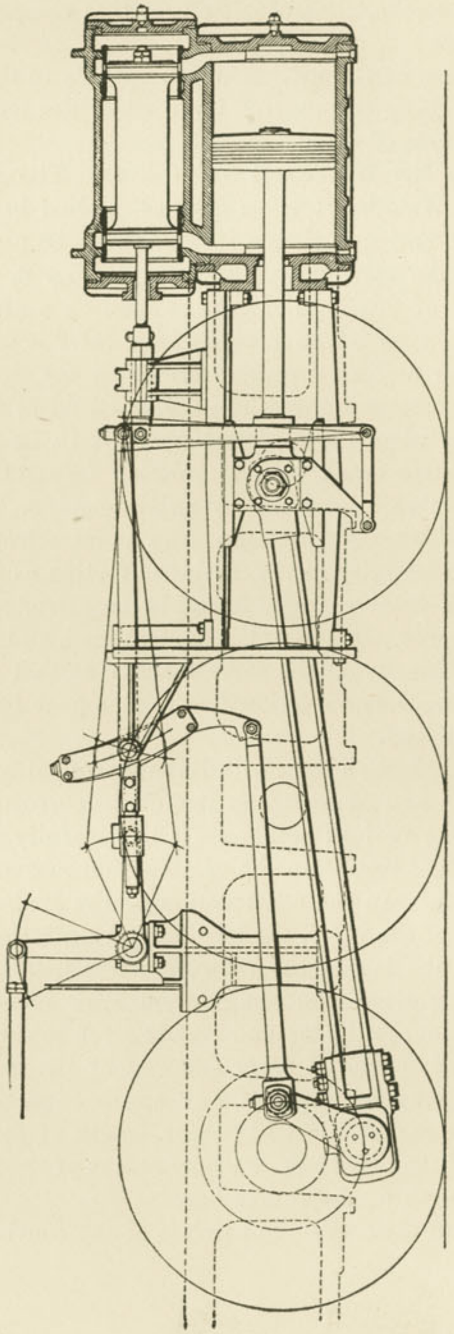


Fig. 2.
WALSCHAERT VALVE GEAR AS APPLIED TO CONSOLIDATION FREIGHT LOCOMOTIVES.

and is usually pivoted to a support on the engine frame or suspended from the guide-bearer. The trunnion is rigid, and there is no chance for twisting strains. The link is actuated by the eccentric rod, which is commonly attached to its lower extremity. The sliding block in the link is secured to one end of the radius rod. The raising or lowering of this rod by means of the reversing shaft shifts the block from one end of the link to the other above or below the pivotal connection. This reverses the movement of the valve with relation to that of the eccentric.

In many cases the gear can be so designed that the motion is transmitted from the eccentric to the valve stem in one vertical plane, so that practically all of the pins can be put in double shear, and all tendency to twist the valve motion is avoided. In some cases it is necessary to have the eccentric and the valve stem in different vertical planes. In such cases some form of rock shaft is necessarily employed to transfer the motion from one plane to the other and give the required solidity to the gear. It is sometimes urged against the Walschaert motion that it requires more moving parts than the Stephenson. This is, however, offset by the better opportunities for solid construction and ready inspection and adjustment.

Proportions of Various Parts. The proportions of the various parts of the Walschaert gear cannot be determined experimentally, nor should any change in setting the valves be made unless the effect of the change is known in advance. It is therefore important that the different parts should be made and set correctly from the beginning, and there will then be no need for changes when the original dimensions are maintained. The difference in this gear for outside and inside admission valves must be considered in setting the eccentric crank, and as the forward motion of the engine should preferably be taken from the lower end of the link, then the eccentric crank will follow the main crank for inside admission valve, and lead the main crank for outside admission valve. The connecting point of the radius bar to the combination lever is above that of the valve stem connection for inside admission valves. The desired maximum cut-off, lead and valve travel determine the size of the lap, and thereby the lap and lead motion is

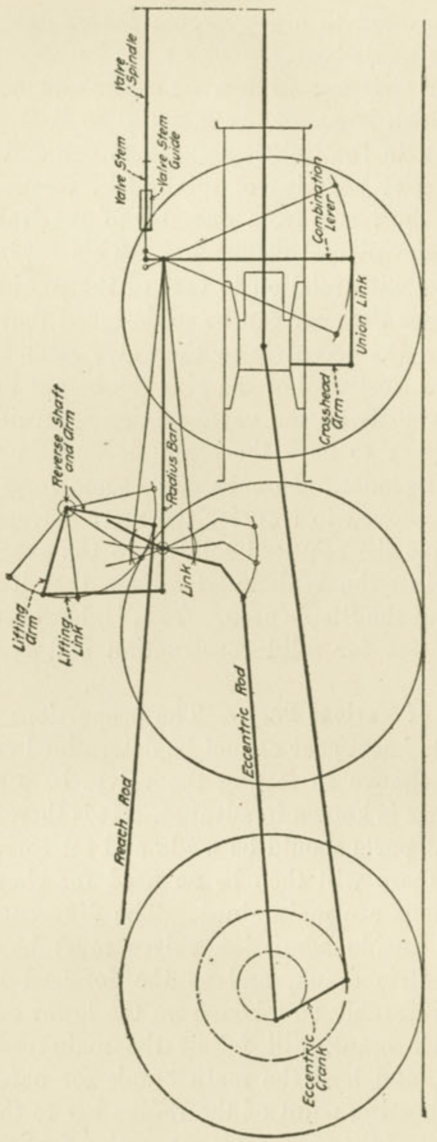


Fig. 3.

NAMES OF THE DIFFERENT PARTS OF THE WALSCHAERT VALVE GEAR.

obtained by the corresponding proportioning of the combination lever.

Arrangement of Radius Bar for Inside and Outside Admission Valves. The end of the radius rod opposite the link is attached to a combining lever, the function of which is to give the required lap and lead to the valve. The lower end of this lever is connected to and travels with the crosshead, while to the upper end are secured both the valve rod and the radius rod, one being placed above the other. The point at which the radius rod is attached to the combining lever becomes a fulcrum. The relative movement of the two ends of the lever must be such that the full movement of the crosshead imparted to the lower end of the lever will give a movement of the upper end equivalent to twice the required lap plus the lead.

For outside admission valves the radius bar is attached to the combination lever between the valve stem and crosshead connections. For piston valves which have inside admission it is attached above the valve stem. The fulcrum of the link lies as nearly as practicable upon a line drawn through the junction of the radius bar and the combination lever, parallel with the center line of the valve stem. The suspension point of the lifter should be located so as to cause the link block to travel as nearly as possible on a chord of the arc described by any point of the link wherever the block happens to be when the link is swung into one of its extreme positions. A lifter, through which the radius bar slides, and which does not slide with the link, answers this purpose, as does also a properly suspended hanger. As there will be some slip of the link bar, however, the suspension point of the hanger is located to suit the most commonly used cut-offs.

In American practice, with the reverse lever in forward gear, the radius rod is generally carried at the lower end of the link, and in back gear the radius rod is carried at the upper end of the link. These connections, however, may be changed, in which case it is necessary to move the eccentric 180 degrees, from a quarter ahead to a quarter behind the main pin.

Eccentric Rod. The length of the eccentric rod should be at least three and one-half times the eccentric throw, and should be made as large as circumstances will permit, with an approximate equal length of the radius and eccentric rods. The point of connection should be as near line of motion of the main rod as this correction for rod angularities will permit. The fore and aft position of this point is determined with reference to the angularity of the eccentric and main rods, so that the link is in exactly its center position when the piston is at either end of its stroke.

Radius of Link. The link should have a radius equal to the length of the radius rod. If this is so, it will be seen that when the engine is on the dead center the link block can be moved from end to end of the link without altering the position of the valve with relation to the ports, and the lead will be constant.

As any variation in the length or relative position of the link, the radius rod and the combining lever or its connections will necessarily change the resulting movement of the valve, it is absolutely essential: first, that the motion shall be correctly designed and plotted; and second, that the detail parts shall be accurately constructed according to the diagram. With these two points assured, the adjustment of the gear on the locomotive is quite simple. The dead center marks on the rim of the driving-wheel and the port tram marks on the valve stem are found in the usual manner. After connecting the gear, any slight variation which may occur between the forward and backward position of the valve can be adjusted by lengthening or shortening the eccentric rod.

Suspension Point of Link. The angles in which the link swings on both sides of its central position are made as nearly equal as possible, and the angularity of the main connecting rod on the cut-off is minimized by properly locating the suspension point in the proper place.

Reversing Walschaert Valve Motion. The Walschaert valve motion is reversed by shifting the position of the radius rod that directly actuates the valve stem from one end of the link to the other. The radius rod is raised or lowered for this purpose by the regular reversing gear, the link being suspended from a bracket by a fulcrum pin, or trunnion, at its exact center.

Hooking Up Walschaert Valve Gear. With this type of gear, when the radius rod is working in either extreme end of the link, it is giving the valve its longest travel, and steam is being admitted

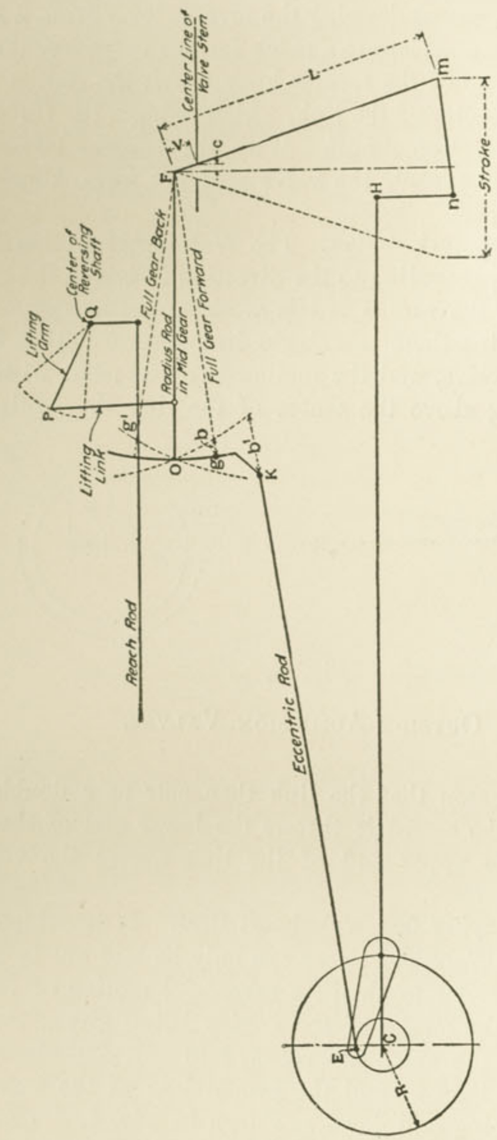


Fig. 4. Method of Laying Out Walschaert Valve Gear.

to the cylinder with the maximum limit of port opening. Hooking up, therefore, means drawing the reverse lever from a full gear corner notch of its quadrant to a notch farther up nearer the center, and this hooking up of the reverse lever draws the radius rod to a point nearer the center of the link, which reduces the travel of the valve and gives earlier cut-off. With the reverse lever in center notch of its quadrant, the valve will not have sufficient motion to open the port.

Direct and Indirect Motion. The Walschaert motion is either direct or indirect, according to the direction in which the engine is running. When the radius rod is working below the center, or fulcrum, of the link there is a single direction of motion from the eccentric to the valve, and the motion is direct; but with the radius rod working above the center of the link the motion is in-

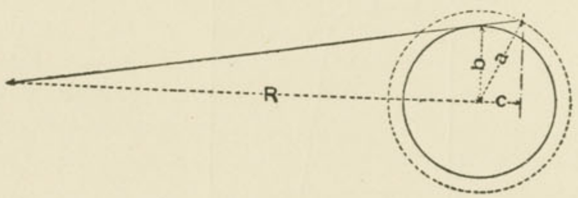


Fig. 5.

OUTSIDE ADMISSION VALVES.

direct, for the reason that the link then acts as a double rocker arm, and when the eccentric throws the lower end of the link in one direction the upper end of the link moves the valves the opposite way.

Method of Laying Out Walschaert Gear. It is evident that a proper design of Walschaert gear can only be laid out by a skilled draughtsman in order to obtain a successful motion of the valve. To begin with, the stroke of the engine being given, the travel, lap and lead of the valve are selected to suit a desired cut-off. The first step is then to find the proportions of the combination lever, the gear being laid down as shown in Fig. 4. The lap and lead are shown at C, the crank radius is R, the crosshead end of the combination lever is called L, and the valve end of this lever is

called Y. Then R×V=L×C, or V=L C÷R, using the connection F of the radius bar as a fulcrum. The length of the combination lever must be determined from the height of the valve stem over the piston rod, which will give an angle of oscillation which does not exceed 60 degrees.

The required horizontal movement or travel of the connecting point F of the radius rod to the combination lever for a given maximum valve travel is found in the following formula:

Let R=radius of main crank.
c=lap and lead.
a=half travel of the valve.
b=half travel of the point F.

Then

$$b=\frac{R\sqrt{a^2-c^2}}{R+c}, \text{ for outside admission.}$$

$$b=\frac{R\sqrt{a_2-c^2}}{R-c}, \text{ for inside admission.}$$

These may also be laid out graphically, as shown in Fig. 5 and Fig. 6. Fig. 5 represents the arrangement for an outside admission valve, and Fig. 6 for an inside admission valve, in which a is equal to the half travel of the valve, R is equal to crank radius, and c is equal to lap and lead. With the limited amount that it is advisable to allow in raising and lowering the link block in reversing the motion, the half motion of the link block, g, may generally be considered to be the same as that of point F, Fig. 4, and by limiting the angle of swing of the link to 45 degrees, the rise or depression of the link block on either side of the link-block becomes Og=b÷tangent d, in which O is the link fulcrum, b=half travel of the point F, and d=one-half the swing of the link in degrees.

Location of Link Fulcrum. Referring to Fig. 4, the vertical location of the link fulcrum, O, should be as near as possible on a line drawn through point F parallel with the valve stem. The eccentric rod connecting pin K should be as near as possible on the same level as the main axle, in order to minimize the effect of the vertical play on the axle. In large engines it is sometimes found necessary to lower fulcrum O and raise connection K in order to avoid excessive throw of the crank. In locating the longitudinal position of the link fulcrum, O, the eccentric and radius rods should both be made approximately the same length.

Position of Eccentric Crank. The exact position of the eccentric crank must be plotted, as well as the position of point K. The eccentric crank must bear such relation to the main crank that it

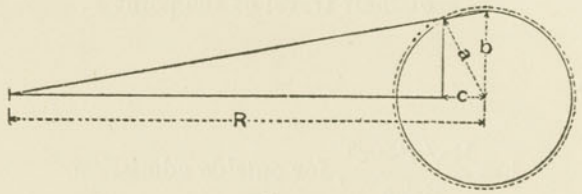


Fig. 6.
INSIDE ADMISSION VALVES.

brings the link in its middle position when the main crank is on either side of its dead center, and the connecting point K must be so located that it swings the link in the required angle *b* on either side of the middle position of the link. In practice it will be found that the point K will be from two to five inches in the rear of the tangent line drawn through the fulcrum O.

The Radius Rod. The suspension point of the radius rod should be so arranged that the link-block is at the same point of the link in its extreme positions of all cut-offs. The curve which does this will have its center near the point F when in its mid-gear position.

There are a large number of other points which enter into the design of the Walschaert gear, and for that reason a model is often considered necessary as a base to work from. It must be remembered that the gear, once set up, provides for no adjustment except by the eccentric rod, which may be lengthened or shortened

until, with the main pin on either dead center, the link has assumed its correct position. When the correct position has been found, the reverse lever may be moved from the back notch to the farthest go-ahead position without shifting the valve. It is well, however, before altering the length of the eccentric rod, to examine the length of the valve stem, so that the correct rod measurements are attained.

INSTRUCTIONS FOR ERECTING WALSCHAERT VALVE GEAR AND SETTING THE VALVES.

The following rules are given by the Baldwin Locomotive Works for erecting the Walschaert valve gear and setting the valves:

1. Check carefully the dimensions of the following parts, rejecting any that are not exactly the same dimensions as the drawing:

a. Valve.
b. Valve-stem.
c. Valve-stem crosshead.
d. Combination lever.
e. Crosshead link.
f. Link radius rod.
g. Reverse link.
h. Location of combination lever on crosshead.
k. Length of eccentric crank.

2. Check eccentric throw to see that it is exactly as specified.

3. Be sure that the guide-bearer is correctly located from the center of cylinder, as the reverse link is usually attached to it, and variation in the location of the link cannot be allowed. If the link is attached to a separate crosstie, similar precautions must be taken to insure its correct location.

4. Exercise great care in the location of the link, so that the fulcrum center is exactly to dimensions from the center of cylinder.

5. See that the reverse shaft center is correctly located to dimensions given, and that the lifting arm and link are of the exact lengths as specified.

6. Connect crosshead gear to valve and radius rod to link, without connecting the eccentric rod to link.

7. Hook up radius rod to exact center of link, and then revolve the driving wheels, seeing that crosshead gear gives correct lead as specified for both front and back admission ports.

For instance, suppose that $\frac{1}{32}''$ is the required lead. With the steam chest open at this time—in the case of a D-slide valve—it should be seen that when the crank pin is at either dead-center the admission port is open $\frac{1}{32}$ of an inch. Without outside admission valves this will be plain, but with piston valves of inside admission a very little steam or compressed air can be used, and by marking the valve stem and noting the blow from the cylinder cocks and the point at which the pressure ceases to escape, the amount of lead can be closely approximated. It should be possible, however, to obtain correct results in this phase of the motion with the eccentric rod connected with the link, for it is required that when the reverse lever is at mid-gear the radius rod shall be centered in the link, and the motion of the latter shall have no influence on the valve or combination lever.

8. Connect link to return crank by eccentric rod, and obtain full travel front and back, and in both forward and backward motions, correcting any errors by lengthening or shortening the eccentric rod as previously noted.

The valves may now be considered to be definitely set, and may be tested to any cut-off points in the usual manner.

A simple additional check may be as follows: Set one side of the engine so that the piston is at its extreme forward position in the cylinder and check lead on the admission port.

In this position it should be possible to move the link block through its entire travel in the link without in any way disturbing the movement of the valve. This operation should then be reversed, and the other side of the engine similarly tried, with the piston located at its extreme backward position in the cylinder.

Types of Walschaert Valve Gear. To suit different classes of engines to which it is applied, the Walschaert valve gear is made in different types. Fig. 7 shows one of these as applied to a 10-wheel locomotive on the Frisco lines. Another is shown in Fig. 8, in which there is provided a guide bar upon which slides a cross-

head. One end of this bar is fastened to the yoke which carries the main guidebars; the other end is attached to the steam-chest. On the yoke is fixed a rocker-box, the bearing of which carries the rocker-arm, to which is fixed the link. Instead of attaching the rod that connects the link and the valve-crank to the bottom of the link, as in foreign practice, the rod is attached to the rocker-arm, which causes the link to rock back and forth, the rocker-shaft forming the axis. The curvature of the link is toward the steam-chest, and the radius is governed by the length of the radius-rod, or from the center of the link to center of the pin on lap-and-lead lever. The

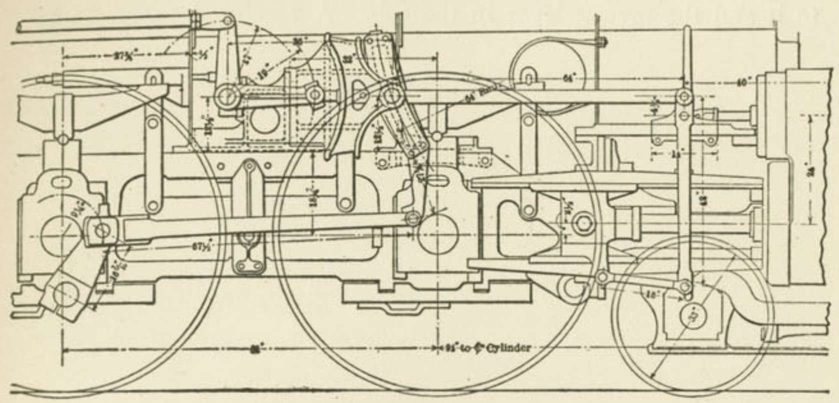


Fig. 7.

Walschaert Valve Gear as Applied to 10-wheel Locomotives.

one end of radius-rod spans the link, and a pin passes through this portion and through the block in link. The lap-and-lead lever has one end attached to the main cross-head by a link which allows for the radius formed by the lap-and-lead lever in passing from one extreme point to the other; the upper end of it is attached to the small crosshead by a pin. To this crosshead is fixed the valve-stem and valve. The distance that the pin attached to small crosshead is above the fulcrum or pin to which radius rod is attached depends upon the amount of lap and lead of valve and the movement of the lower end of lever. Without this lever in the valvegear the valve would be in the center of its travel, when main crank pin would be on either center. In order that the radius-rod which spans the link shall pass up and down free, when it is raised or lowered to reverse the motion of the engine, the rocker-shaft at the link side has a plate the size of the link, to which the link is fastened at each end. Spacing-blocks are between the side of link and the plate, forming a clearance space for the end of radius-rod. In this case the radius-rod has the suspension-link attached at a point between the lead-lever and the link, the reverse-shaft being above the guide bars and close to boiler. A reach-rod is connected to another reversing-arm and cross-shaft, which also has another arm connected to it and the reverse-lever in the cab. A reach-rod passes to the

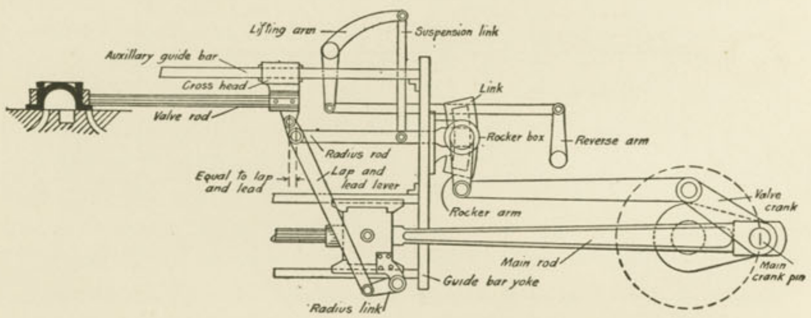


Fig. 8.

Modifications of the Walschaert Valve Gear.

reversing-shaft on the other side of engine for the gear of that side. By placing the reversing-arms to reverse the engine, and also to change the point of cut-off, the valve crank-pin leads the main crank-pin in running in the forward motion, and the link-block will be in the bottom half of link, a position opposite to that of the Stephenson gear, the Walschaert being equivalent to a direct motion, while the Stephenson is indirect, when using rocker-arms and using a valve taking steam, as shown in Fig. 6. When using an internal admission-valve as a piston-valve, the link-block would have to be in the top half of the link, and the valve would move in an opposite direction to that of the piston-head in the first part of its travel or while opening the steam-port.

In order that the link-block should be in the bottom half of the link in the forward motion, with an internal admission-valve using the Walschaert gear, the valve-crank should be placed to follow the main crank-pin in either case. The valve crank-pin and the main crank-pin are set at 90 degrees apart, or at right-angles. In the drawing the valve is shown as being in the lead, or just opening the steam-port, the crank-pin on the back center and in the forward motion; the lead is equal at all points in the motion. The position of valve crank-pin, or distance from center of axle, is exaggerated in the drawings, which are diagrammatic only.

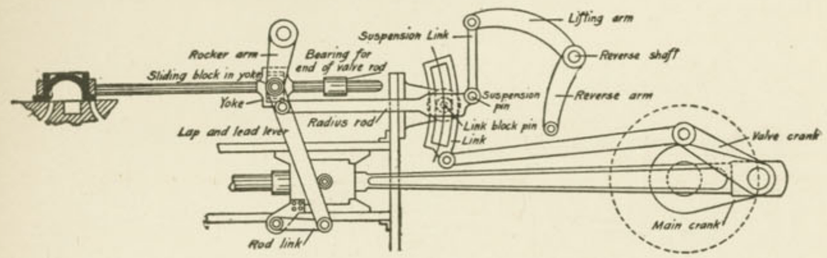


Fig. 9.

Arrangement of Walschaert Valve Gear, Using Short Connections Between Valve and Valve Lever.

Fig. 9 shows another modification, in which the design requires the use of short connections between the valve and lead-lever. In this case there is used a rocker-shaft above the main guide-bars, which has two rocker-arms on it. This shaft is carried in a bearing; the upper end of lead-lever is attached to the one rocker-arm as shown. The valve-rod has a yoke on it, forming a part thereof,and in this yoke is a sliding-block; the pin of the other rocker-arm fits in this block. The back end of valve-rod is carried in a bearing. This construction permits of a very short rod and connection. The lifting or suspension-link in this case is attached to the extreme outer end of radius-rod, which spans the link, and has an extension, to which the suspension-link is attached. The usual reversing-shaft is used in this case. The driving-link is carried by a shaft, upon which it swings or oscillates, and on the lower end of the link there is an extension, drilled to receive a pin. To this extension is connected the rod from valve-crank, and it differs from Fig. 6 in this respect, that there is no rocker-arm to operate link. The general principle of this gear remains the same. The modifications are made to suit the design of locomotive. In using this motion there is no gear under the boiler, the eccentrics and straps are discarded, and all moving parts are visible to the engineer and inspector.

Walschaert Valve Gear for Pacific Type Locomotive. The application of the Walschaert type of valve gear to a Pacific type

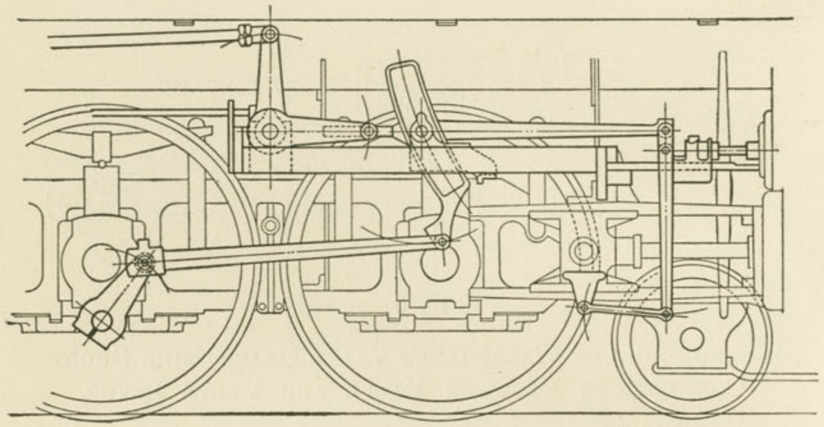


Fig. 10.

WALSCHAERT GEAR AS APPLIED TO A PACIFIC TYPE LOCOMOTIVE.

locomotive presents difficulties not encountered with other wheel arrangements. This is due to the proximity of the front driving wheels to the cylinder, necessitating the placing of the guide yoke very far forward, and preventing its use as a support for the link. If, on the other hand, the link is placed back of the driver, being hung on an extension of the frame crosstie, as is often done with the ten-wheel type, it makes the eccentric rod so short as to introduce very serious errors of angularity. These difficulties have been solved by placing a supplementary frame outside of the front driver, on which the link can be supported at the most desirable point. This construction adds considerable weight and a number of extra parts

to the locomotive, but it is practically the only solution of the problem.

One arrangement of this gear used on the Pacific type locomotive by the American Locomotive Co. is shown in Fig. 10. The valve gear is practically all in one vertical plane, there being but two and a half inches difference between the center of the pin on the eccentric crank and the valve stem. One and a half inches of this is in an offset in the eccentric rod, and one inch is obtained at the connection of the radius bar to the combination lever. The valve chamber is thrown four inches outside the center of the cylinders, which presents no objection other than the increase in the weight of the cylinder casting and slightly longer steam passage, provided the clearance limits are not exceeded.

Walschaert Gear Used on Mogul, or 2-6-0 Type. Although the advantages of the use of the Walschaert valve gear are not so apparent, when applied to the Mogul type of locomotive, it is being used on a number of roads in connection with this type of locomotive. With this type of locomotive a simple form of Stephenson gear without complications can be used, so that the valve gear, being outside the frame, may be said to be the principal advantage of the Walschaert motion. Fig. 11 shows a Mogul engine used on the Vandalia railroad, equipped with this type of valve gear. The gear is designed to give straight line motion with the combination lever on the outside of the guides, and the valve chamber is set four inches outside of the center of the cylinder for this purpose. The lifting arm connects to the radius rod through a slip joint, making a simple and satisfactory arrangement. The extension of the valve stem is guided by a support from the top guide bar.

Walschaert Gear Used on the Consolidation Type. The Walschaert valve gear design as applied to the Consolidation locomotives is an excellent example of one of the simplest arrangements of this type of gear. It may all be practically located in one vertical plane, and there need be only one reversing shaft and comparatively few moving parts. An arrangement of this kind is shown in Fig. 12, which represents the side elevation of a Consolidation type of freight locomotive, built for the New York Central and Hudson River Railroad by the American Locomotive Co.

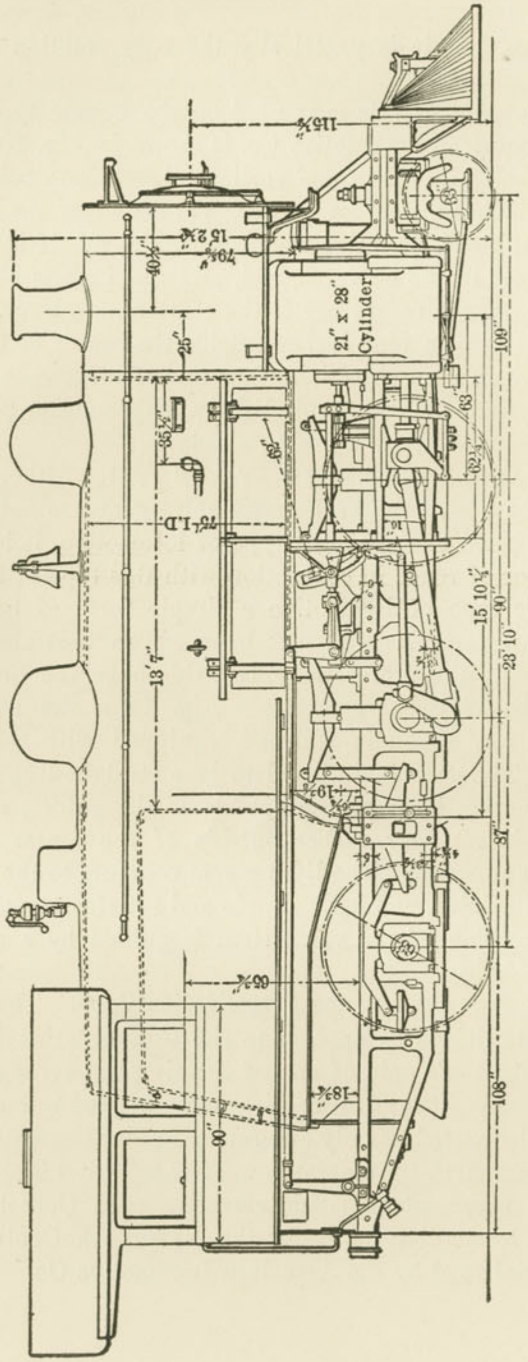


Fig. 11.

MOGUL LOCOMOTIVE USED ON THE VANDALIA LINES EQUIPPED WITH WALSCHAERT VALVE GEAR.

Helmholtz Modification. Among the various modifications of the Walschaert gear the one made by Helmholtz possesses some advantage. This modification consists in making the link straight, the radius bar being connected to the lifting link instead of the link block. The curving of the link is compensated for by the reversing shaft or lifting arm fulcrum being located in a given position above the link, so that the locus of the suspension point of the lifting link forms an arc of a circle with its chord perpendicular to the center line of the radius bar in its center position. The radius of this arc bears the same relation to the length of the radius bar as the distance of the radius bar connection above the link block bears to the length of the lifting link, which results in that this connection is moving in an arc with a radius of the length of the radius bar, and the same motion of the valve is obtained as in the direct Walschaert gear.

Two advantages may be claimed for this modification, of which one is the straight link being simpler to make than the curved one, and the other is that on large piston valve engines with inside admission the link fulcrum can be lowered by the amount the radius bar connection falls over the link block, whereby the eccentric connection rod can be brought closer to the center line of the axle with less length of link and eccentric throw. It has, however, the disadvantage that there is little choice in the location of the reversing shaft or lifting arm fulcrum, a proper position for which is hardly obtainable on all types of engines, and admits of no other method of lifting the radius bar in linking up or reversing the engine.

Reuleaux and Zeuner Diagrams. Fig. 13 shows a combination of two diagrams which may be used for designing the valve motion, namely, those of Reuleaux and Zeuner, which coincide exactly as to the different valve events, which may be found as follows:

The distance AB represents the travel of the valve as well as the stroke of the engine, though in different scales, which makes no difference when the cut-off is always expressed in fractions or per cent of AB. The maximum cut-off is determined upon to be AR. Draw a perpendicular line RC from AB until

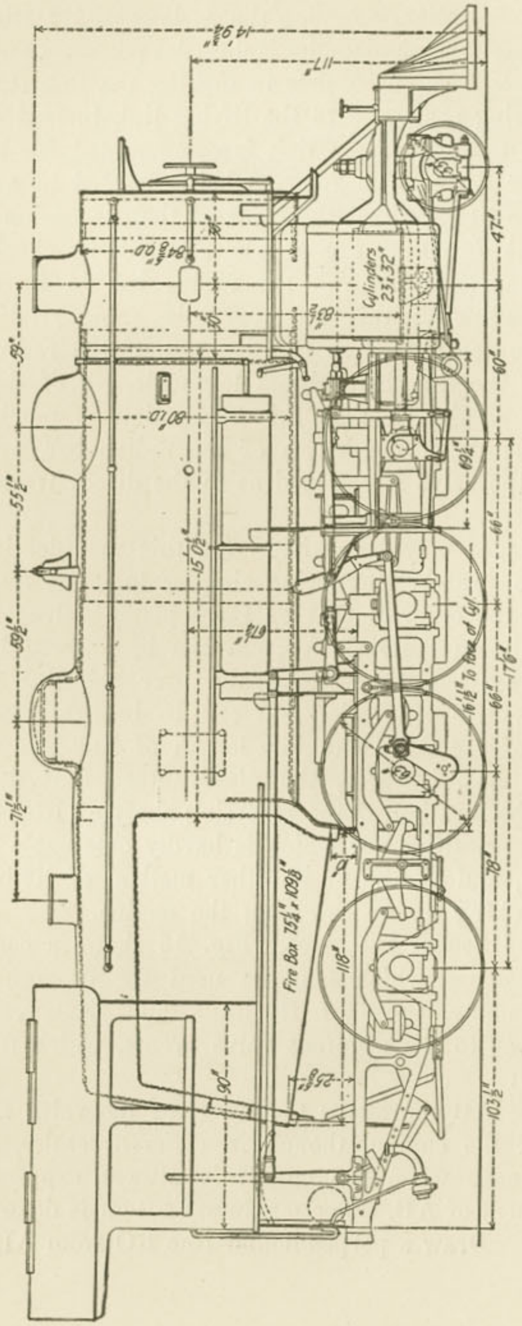


Fig. 12.

WALSCHAERT VALVE GEAR AS APPLIED TO CONSOLIDATION TYPE FREIGHT LOCOMOTIVES USED ON NEW YORK CENTRAL AND HUDSON RIVER R. R.

it cuts the arc ACB. Next decide on a desired lead, and, with that as a radius, draw an arc with A as a center. Draw a line from C tangent to the lead circle around A, when the lap of the valve is found to be equal to the perpendicular distance from the line CS to the center O of the diagram. The crank will then be in position OS when the valve commences to open,

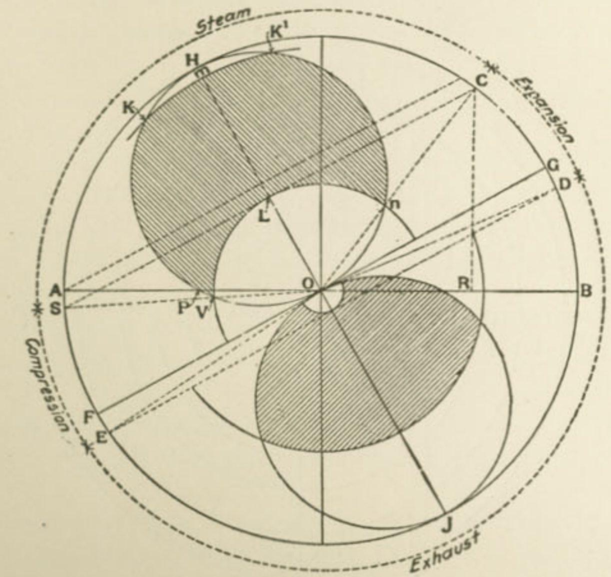


Fig. 13.

VALVE DIAGRAM USED FOR DESIGNING WALSCHAERT VALVE GEAR.

or the angle AOS in advance of the dead center, and on OC at cut-off. The valve is found in its middle position when the crank is on OG, which is drawn parallel to SC through the center O. Extend this line to F, and with the exhaust lap as a radius draw the exhaust lap circle on the opposite side of the line GF, and draw DE tangent to this circle, when OD is the position of the crank at the release point. From this point the exhaust remains open until the crank reaches the position OE, when it closes and compression takes place until it again reaches OS for admission, and one revolution is completed.

By placing the Zeuner diagram upon this, draw HJ perpendicular to FG, and with the radius, OH, of the eccentric circle as a diameter, draw the admission valve circle OVHnO and the lap circle with the steam lap as a radius, and find the intersection

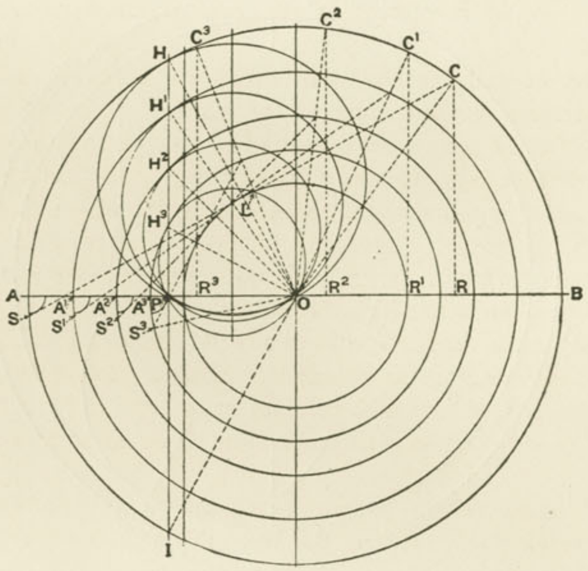


Fig. 14.

VALVE DIAGRAM SHOWING DIFFERENT CUT-OFFS.

occurs at V, both with the circles and the previously laid down admission line OS and the cut-off point at the intersections at n. On the line OH set off the width of the steam port from L toward H equal to Lm, and with Om as radius draw the arc KmK′. The shaded figure enclosed by the letters VKK′nL represents the steam port opening during the admission period, and the width of the port opening at any desired position of the crank is found by measuring the distance radially from O between the lap and valve

circles on the port line, as the case may be, on the desired crank position.

The exhaust openings are determined in the same manner, and are shown on opposite side of FG, where the crank passes through the arc DJE during the exhaust period with a positive exhaust lap of the size EF. When the exhaust edge of the valve is line and line, this arc becomes GJF, or 180 degrees, and when a negative lap (clearance) occurs, the duration of the exhaust period exceeds the half revolution of the crank. The various events are indicated around the eccentric circle on the figure as they take place during a complete turn of the crank.

In Fig. 14 the eccentric and admission valve circles are shown at different cut-offs, where each set of lines and circles is governed by the same explanation as those of Fig. 8, where the admission points S, S^1, S^2, S^3, correspond to the closing positions C, C^1, C^2, C^3, cut-off points R, R^1, R^2, R^3, etc. On OH we have the full travel valve circle and OL the lap or radius of the lap circle, the latter being the same for all cut-offs as well as the lead, the radii H^1, H^2, H^3, etc., of the eccentric circles or diameters of the corresponding valve circles terminate on a line HP drawn perpendicular to AB and at a distance from O equal to that of lap and lead.

When the reverse lever is in its center position, the diameter of the valve circle falls on the line AB, and is equal to lap and lead. Continuing in back position, the same method is repeated, and OP would be the full travel valve circle diameter, or the same as the eccentric radius for the valve travel. Any desired cut-off position may be laid out in same manner as that in Fig. 8, which shows all the valve events for a complete revolution of the axle.

The movements are, in actual practice, not so regular as the circles indicate, on account of the angularities of both the main rods and the eccentric rods, whereby irregularities enter in the problem that must be compensated for. In selecting the suspension points, the following three points should be carefully considered: First, the connecting point of eccentric rod and link; second, the position of the lifting link suspension point; and third, the relative height of the crosshead connection point of the union bar to the corresponding point of the combination lever.

It is not necessary to lay out the valve diagrams except where a given cut-off per cent is wanted. This is the most convenient way to find the required lap.

General Instructions on Adjusting Valves. In setting the Walschaert valve gear it must be borne in mind that two distinct motions are in combination, viz.: the motion due to the crosshead travel and the motion due to the eccentric throw.

The crosshead motion controls the lead by moving the valve sufficiently to overcome its lap, by the amount of lead in both front and back positions. The eccentric throw controls the travel and reversing operations. It will be seen from Fig. 11 that the movement due to the eccentric, without the crosshead motion, would place the valve centrally over the ports when the piston is at the extreme end of the stroke. The combined effect of these two motions, when the parts are properly designed, gives the required movement of the valve, similar to that obtained by the use of a stationary link. To reverse the engine the link block is moved from end to end of the link, instead of moving the link on the block. This operation is accomplished by means of a reversing shaft connected with a reversing lever in the cab.

Walschaert gears should be correctly laid out and constructed from a diagram, as the proportions cannot be tampered with by experimental changes without seriously affecting the correct working of the device. The only part capable of variation in length is the eccentric rod, which connects the eccentric with the link. This rod may be slightly lengthened or shortened to correct errors in location of the link center, from center of driving axle which carries the eccentric.

The eccentric usually assumes the form of a return crank on one of the crank pins, and its center is at right-angles to the plane of motion, viz.: at ninety degrees to a line drawn from the point on the link at which the eccentric rod is attached through the center of the driving axle. This eliminates the angular advance of the eccentric, and allows the use of a single eccentric for both forward and backward motion. The throw as specified must be correctly obtained, and great care taken that the position shown in

the design be adhered to. The crank representing the eccentric is permanently fixed to the pin, and the slightest variation will be detrimental.

When the engine is assembled, the throw of the eccentric should be checked up by the specifications, and any error should be at once reported, in order that the mistake may be rectified by either correcting the position of the eccentric or by a change in the design of the other parts to compensate for the error.

Another Method of Adjusting Valves with Walschaert Gear. The lap and lead are determined by the proportion of the arms of the combination lever and the stroke of the piston. The amount is found by turning the engine from one dead-center to the center in any cut-off position. The motion should be adjusted as follows:

1. Ascertain the position of the eccentric crank by the following method: Mark the position of the link relative to its middle position on both of the dead-centers of the main crank. If the position of the link is the same in both cases, the eccentric crank position is correct; if not, the eccentric crank should be shifted until this occurs, or is as nearly so as possible.

2. With the cranks on the dead-center, the eccentric rods should be lengthened or shortened until the link valve 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. The link position may be observed by the usual tram marks on the valve stem, or direct by marks on the link pin as may be found most convenient with the link block in full gear, preferably ahead.

3. Before this change in the eccentric rod is 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 it may be that the length of only one rod need be changed.

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

5. 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.

6. 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 links, in order to meet the requirements of the first condition.

7. The tram marks of the opening moments at both ends of the valve should be marked on the valve stem, and the latter lengthened or shortened until equal leads at both ends are obtained.

8. Within certain limits this lengthening or shortening may be made on the radius-bar, if it should prove more convenient; but it is desirable that its length should be so nearly equal to the radius of the link that no apparent change in the lead should occur in moving the link block.

9. The lead may be increased by reducing the lap, and the cut-off points will then be slightly advanced. Increasing the lap produces the opposite effect on the cut-off and reduces the lead the same amount. With good judgment these quantities may be varied to offset the irregularities inherent in transforming rotary into lineal motions.

10. The valve events are to a great extent dependent on the location of the suspension point of lifter of the rear end of the radius-bar when swinging lifter is used, which requires that this point should be properly laid out by careful designing; or, if convenient, it is preferably determined by a model, as irregularities due to the incorrect location of this point cannot be corrected by the other parts of the gear without more or less distortion of same.

WALSCHAERT VALVE GEAR BREAKDOWNS AND REPAIRS.

In case of accident, if any of the rods or connections are broken, it is advisable, if possible, to disconnect the eccentric rod. The combining lever should be uncoupled from the crosshead and securely fastened in forward position. If for any reason the eccentric-rod cannot be taken down, the radius-rod must be removed in order that no motion may be imparted to the valve. The valve can then be placed in central position, and held either by suitable blocking or by clamping the valve rod. This seals both steam ports and cuts out the cylinder on the damaged side.

Broken Crank-pin or Steam Valve. If a crank-pin, steam valve or the rod connecting the crank to link should break, the ports must be covered and the broken parts taken down. Disconnect the lead-lever from main crosshead, taking care that the lead-lever clears it, and then clamp the valve in position. In the case where the ports must be covered the valve should be set in the center of its travel, covering the ports. When using the types of gear which has the valve-rod driven by the rocker-arm and yoke, the pin can be taken out of the rocker-arm with it. The rest of the gear can remain hooked up. The main rod must be taken down in all cases requiring the port to be covered.

Broken Link. Should a lifting arm or suspension link become broken, and it is desired to run on both sides, a block should be put in the link between link-block and link, top or bottom, depending on the direction in which the engine is running.

Broken Lap-and-Lead Lever. Should the lap-and-lead lever become broken, the ports should be covered, the lever taken down, and the radius-rod and valve fastened in center of seat.

Broken Radius-rod or Link-block. Should a radius-rod or link-block pin break, the radius-rod should be taken down, the block taken out of the links, the valve centered and clamped to hold in center of seat. The lap-and-lead lever can remain in position, and can swing from rocker-arm if used on crosshead. Care must be taken that the valve rod is held rigid. On many rods a clamp is furnished and carried on every engine, by means of which the valve stem can be firmly secured in a position that places the valve squarely over the ports. If no clamp is at hand, the pressure of the steam on the valve will give enough friction resistance to hold the valve in place; but a clamp should be used when obtainable.

Broken Valve Stem. If the valve stem should break, disconnect the radius-rod and center the valve, blocking or clamping it if possible. Leave the combination lever in place, providing that, as the end swings forth and back, it does not strike the projection of the pin that connects the main rod to the crosshead. The slide, from which the valve stem has been disconnected by breakage, should be placed on the slide bar in a position where it will not interfere with the combination lever, and it should be blocked in that position so that the motion of the lower end of the combination lever will not result in pushing the valve off center.

Broken Main Rod. In case of a broken main rod on an engine equipped with a Walschaert valve gear, take down the parts of the broken rod and disconnect the radius-rod. If the valve is of inside admission, push it to the forward end of the steam chest and clamp the valve stem or block the slide to hold it in position. If the valve has outside admission, it should be drawn to the back end of its travel and held there. In either case it is the object to keep the front admission port open for steam to enter the cylinder and the back port open to the exhaust. Then move the crosshead as far as it will go until the piston is against the back head of the cylinder. This is called steam blocking, and while steam is being used the piston will stay placed; but when steam is cut off, the piston is liable to move, so that it is best to block the crosshead in that position. As there will be no movement of the combination lever, it should not be disturbed. The eccentric rod will, of course, continue to give the regular motion of the link, but the action of the link will have no effect, as the radius-rod is disconnected from its suspension bar and combination lever and is centered in the link.

If the front cylinder head should blow out, the radius-rod should be disconnected, the valve centered and the back cylinder cock removed.

If the piston rod should become bent in an accident, the radius-rod should be disconnected and the ports covered by centering the valve. The main rod should also be taken down.

Broken Eccentric Rod. If the eccentric rod should break, throw the reverse lever to the forward position, in order to lower the radius-rod. Block the bottom of the link and disconnect the suspension bar from the radius-rod, and the radius-rod from the combination lever. Raise the front end of the radius-rod so that it will not interfere with the rest of the gear, and fasten its forward end to anything solid, in order to keep the link from rotating. Block the valve and proceed.

Disconnecting Radius-rod. In all cases where the radius-rod must be disconnected in cases of accident the proper method is to first place the reverse lever in the center notch of the quadrant, in

order to get the back end of the radius-rod and the link block in the exact center of the link. Insert pieces of wood between the bottom of the link and link block, and secure them in position, in order to support the back end of the radius rod at the center of the link. Then disconnect the hanger between the lifting arm and radius rod, and take out the pin from the front end of the radius rod in its connection with the combination lever, suspending it by anything that will support its weight, as it does not have any motion imparted to it. Then center the valve by blocking or otherwise. When the engine has started, watch carefully that the combination lever does not strike the wrist-pin.

REVIEW QUESTIONS.

WALSCHAERT VALVE GEAR.

1. How long has the Walschaert valve gear been used on locomotives?

2. How does the Walschaert valve gear differ from the Stephenson link motion?

3. What are the advantages of a constant lead with any valve motion?

4. What is the function of the combining lever?

5. Give six different reasons which have led designers to apply the Walschaert valve gear to locomotives.

6. Describe briefly the general arrangement of the Walschaert valve gear.

7. How are the lap and lead determined?

8. If the valve motion did not give good results, what would be the first thing to do?

9. Suppose the suspension link became broken, how would you proceed?

10. What would you do if one crank-pin should break?

11. Suppose a main rod should break, how would you go about adjusting the valve gear?

12. What precautions must be taken when disconnecting the radius-rod.

13. When is a Walschaert motion direct and when is it indirect?

14. What part of the valve gear can be varied in length?

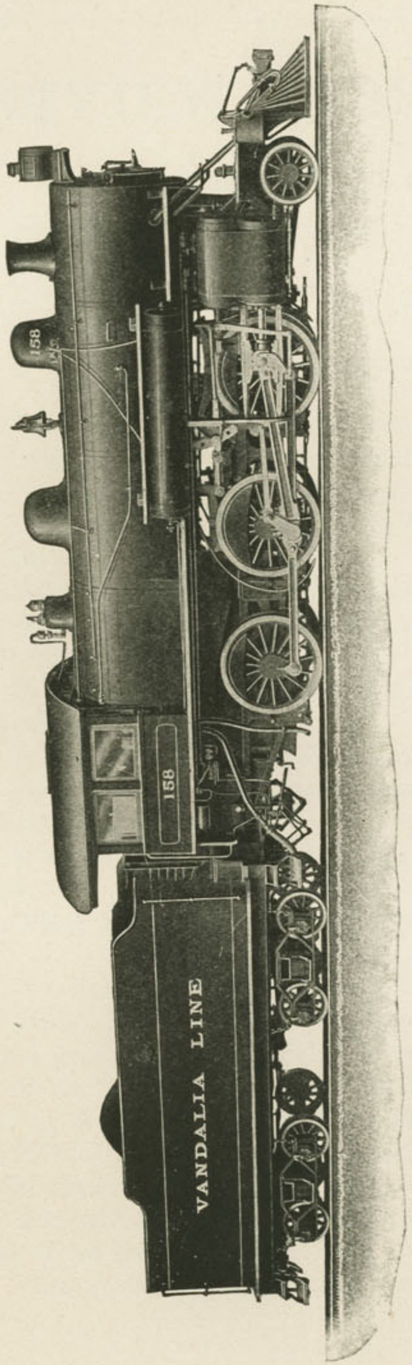
15. What kind of eccentrics are usually used with the Walschaert valve gear?

16. Explain why the valve will not allow excessive compression with the Walschaert type of valve gear.

17. How is the radius bar attached to the combination lever for outside admission valves?

18. What ratio should the length of the eccentric rod bear to the length of the eccentric throw?

19. What should be the radius of the link?



MOGUL TYPE FREIGHT LOCOMOTIVE
(American Locomotive Company)

The Steam Engine Indicator

The Valve of the Indicator. While there has always been considerable discussion as to the value of using an indicator on the locomotive, there is no doubt that for the purpose of setting the valves and sometimes in finding the efficiency of the engine, the indicator is an extremely valuable instrument. A locomotive, however, will often use steam economically and at the same time burn a considerable amount of coal. This may be due to several reasons principally through the action of the exhaust. A good indicator card should show prompt admission, sharp cut-off and release, and small back pressure. With such a card, the steam exhausts very rapidly from the cylinder, whereas, when the exhaust is allowed to open slowly giving a mutton-leg form of card, the steam exhausts slowly and has a minimum effect upon the fire. The principle reason, however, why indicators are not more frequently used on locomotives is because they do not show the efficiency of the boiler. Even though the cylinders of the locomotive use steam economically, it is no indication that the boiler is working efficiently, and with an uneconomical boiler, it is almost useless to attempt to save steam in the cylinders.

The use of the indicator, however, as an aid to the traveling engineer, is recommended by the best engineers, and that it has not been more used by him is due to the lack of instruments, the difficulty encountered in piping the cylinders, the application of reducing motions to the different types of locomotives and the other numerous duties which he is required to perform.

The most common method employed and used as a leverage to increase the efficiency of men and locomotives is to arm the traveling engineer with a copy of the performance sheet for a previous month and a letter of the Master Mechanic calling attention to the poor showing or the unsatisfactory performance of the men and locomotives that have made a record below the average in miles run per ton or in pounds of coal used per hundred ton mile. If the traveling engineer were equipped with the proper indicator outfit, it would give him valuable aid in discovering, in many cases, whether the lack of efficiency was caused by the improper setting of the valves.

There is no more important duty after safety, time and service are cared for, than that of saving fuel. A poor showing is usually chargeable to the mechanical department and poor power conditions. The operating department is entitled to credit in proportion to reductions in overtime and delayed time, better train movement, train tonnage, handling of traffic, efficiency of train crews, etc., when the showing is favorable, and should also be considered when the performance is unfavorable.

In nearly every electric power plant steam is used for generating current. Engines are indicated frequently, coal and ashes are weighed, and the evaporation of water per pound of coal is recorded to determine the efficiency of boilers and engines, and any leakage is properly looked after and immediately remedied, and the cost of furnishing power is given out, showing the economy, which so far is in favor of the electric and against the steam locomotive. If the same attention was given to the consumption of coal and maintenance of steam locomotives, and the losses were looked after and remedied as promptly, the reduction in coal bills and cost per hundred ton mile, as well as improved power conditions, would be improved.

An indicator card that will show a fine steam distribution is of no particular value unless it is followed by a reduced cost per mile or ton mile for fuel, as an indicator card from the perfectly adjusted valve gear would not indicate the efficiency of the boiler, adjustment of draft appliance, economical train movement, tonnage rating or the skill of the engineer and trainmen in getting the train over the road.

If a few trips were figured with the same engine and same crew, first with engine valves improperly set, and then with them set accurately, the saving in coal would make it apparent that the indicator should be more often used than it has been in the past. The indicator will show the pressure of steam at the beginning of the stroke; the amount of pressure during the period of admission; the point of cut-off; the pressure during the expansion of the steam; the point of the stroke at which the exhaust opens; the back pressure on the piston; the point at which the exhaust

is closed; the amount of compression; and the horsepower of the engine.

Having this data, the operation of the valves is exactly known, so that if they are incorrectly set, they may be adjusted to give the best steam distribution under the given conditions. Should the engine, with the proper valve setting, run uneconomical, then the attention must be directed toward the boiler; which, of course, must always be considered in connection with the economy of the locomotive.

The indicator is an instrument for producing a continuous record of the varying steam pressure and the motion of the piston in an engine cylinder during a complete rotation of the shaft. It is used to show just when and how the pressure changes, and so to ascertain the time of opening and closing the valves, or to detect leakage or rapid condensation of steam. It is also used to measure the work done by steam upon the engine piston, and thereby to furnish an indication of the horse-power. For assistance in setting valves it can be applied with great advantage to engines, pumps, compressors, and various other machines, but a greater value lies in its application for measuring power developed or work done by steam, air, gas, water, or any other elastic vapor or liquid confined under pressure. For this latter purpose no other instrument is available and the indicator is indispensable.

In the early days of engineering, when steam engines were used only for pumping water before the application of the crank, connecting-rod, and fly-wheel had made them available for imparting circular motion to shafting, and thus applicable for general power purposes, they were designed to receive steam at full pressure from the beginning to the very end of the stroke, and then to close the admission and simultaneously open the exhaust so that the steam escaped without expansion. The piston was driven by a constant pressure throughout its working stroke, and was resisted by a constant lower pressure during the exhaust stroke. With such an engine it was easy to calculate the net work done per revolution.

When James Watt began to build engines for the English cotton mills he found that better economy was secured by cutting off the steam supply somewhere near mid-stroke, and then allowing expansion to take place until the stroke was finished. He found that the pressure, the driving force of steam, diminished rapidly after cut-off, and that consequently less work was done by an engine of a given size, but the steam consumption decreased much faster than the work, and as a result the engine was more economical. Soon afterward the gradual increase in speeds necessitated closing the exhaust valve before completing the return stroke, so that the compression thus introduced might cushion the piston and bring it to rest without shock. Thus the forward stroke was caused by a pressure which was constant up to cut-off, and then decreased (though no one knew just how fast), and the return stroke was made against a pressure, constant until the exhaust valve shut, and then increasing rapidly (though

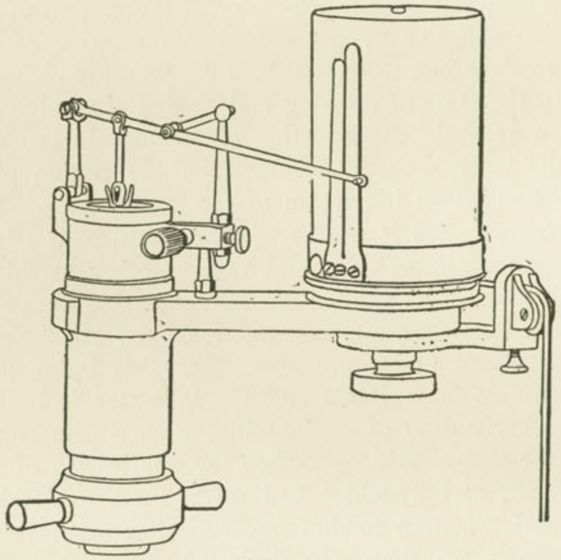


Fig. 1

to an unknown extent) during compression. A device for recording this fluctuating pressure and measuring its net effect in performing work was much to be desired, for upon such measurement depended the whole problem of improving steam engine economy by a proper setting of the valves. Realizing this necessity, Watt invented the indicator. Though his original instrument produced no record, and would be of little use for the high speeds and high pressures of to-day, he was able to make invaluable use of it in perfecting the engines built by his firm. Since that time the indicator has been greatly modified and improved.

It is now manufactured by many different companies, each of which has special details of construction, but the essential features are the same in nearly all the well-known instruments.

What may be regarded as the standard form of steam engine indicator is shown in Figs. 1 and 2, the former made by the Star Brass Mfg. Co., and the latter by the Crosby Steam Gage Co.

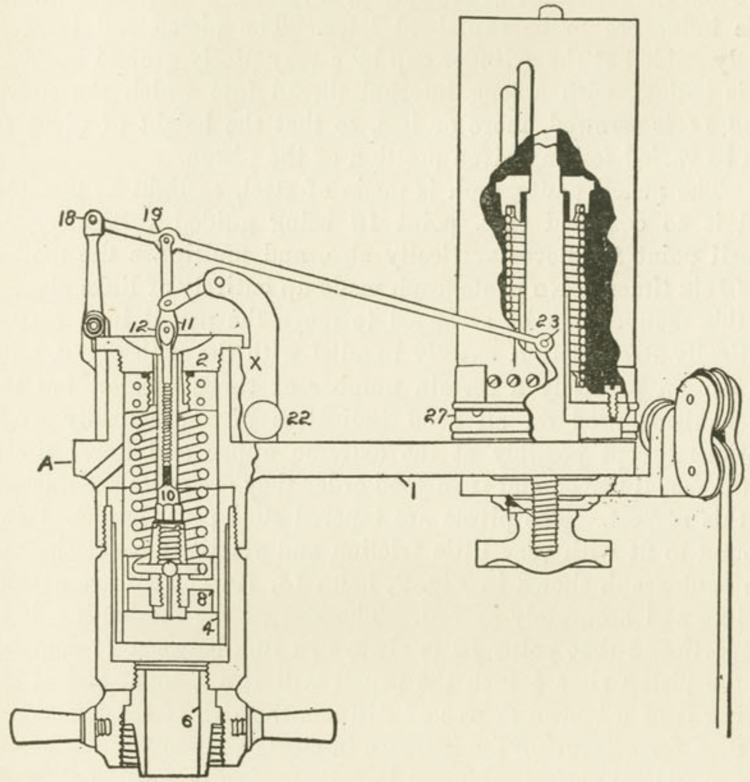


Fig. 2

These instruments differ principally in the form of pantograph used for the pencil mechanism; internal details of the cylinder and drum are almost alike in both.

Referring to Fig. 2, steam from the engine enters at *6*, filling the lower part of the cylinder and its surrounding jacket space. Upward pressure on the piston *8* is resisted by a spring above it, the top of which (see Fig. 34c) is screwed fast to the cylinder cap *2*, and thus held at a fixed height, while the bottom can move up and down with the piston in response to variation in steam pressure. At *A* there are several vent holes of ample size communicating with the atmosphere, so that steam leaking by the piston cannot accumulate pressure above it. The height of the piston at any instant depends solely upon the steam pressure and the resistance of the spring, subject to slight and unavoidable influences to be explained later. The piston rod is accurately guided at the cylinder cap by a very nicely ground bushing. It is hollow, with a long internal thread into which the *swivel head 11* is screwed, more or less, so that the height of pivot *12* can be varied for any given position of the piston.

The pencil pantograph is made of steel, as light as possible, and is so designed that, point *12* being guided vertically, the pencil point *23* moves vertically also, and multiplies the motion of *12* six times. No pantograph made up entirely of links pivoted in this manner can be arranged to move the pencil in a mathematically straight line, exactly parallel with the path of *12*, with its motion precisely a certain number of times greater, but the mechanisms used on all good indicators give practically exact motions except possibly at the extreme upper and lower limits of the pencil travel, and if in good order they are quite satisfactory in this respect. The pivots are tapered steel pins, hardened and ground to fit with very little friction and yet little backlash. In the pantograph shown in Fig. 2, holes *18*, *19*, and *23* are exactly in line and accurately spaced. The rest of the mechanism is so proportioned that point *12* is always in line between *17* and *23*. If the piston rises $\frac{1}{6}$ inch the pencil will rise 1 inch, and if the spring is of a known degree of stiffness the rise of the pencil can be used for measuring the increase in steam pressure.

A helical spring subjected to compression or tension shortens or lengthens proportionally to the force applied. If 1 pound compresses it $\frac{1}{240}$ inch, 2 pounds will compress it $\frac{2}{240}$, and so on provided the elastic limit is not exceeded. Now the indicator described, and almost all others of the standard type made for steam engines have pistons ground to such a diameter that the area is exactly $\frac{1}{2}$ square inch. Suppose that the spring in Fig. 2 is of such a scale that it shortens $\frac{1}{240}$ inch per pound force applied, and that when atmospheric pressure exists above and below the piston the pencil *23* stands at a given height. Then suppose a steam pressure of 80 pounds per square inch is exerted below the piston. Its upward force, $80 \times \frac{1}{2}$ or 40 pounds, will compress the spring $40 \times \frac{1}{240}$ inch or $\frac{1}{6}$ inch, so that the pencil will rise $6 \times \frac{1}{6}$ inch or 1 inch. Such a spring is stamped by the makers with the number 80, and is referred to as an *80-pound spring,* or *the scale of the spring* is said to be 80 pounds.

The paper drum in Fig. 2 is removable from its base *27* by a straight upward pull. A helical spring inside can be adjusted for any desired torsion, and serves to return the drum to position after the cord has been pulled out and then let back. The cord is to be connected to a proper mechanism for reducing the motion of the engine crosshead in such a manner that as the engine piston moves to and fro the indicator drum will oscillate about its axis, and its circumferential displacement at any given time will always be in direct proportion to the piston displacement from the beginning of the stroke. Fig. 3 shows a pair of indicators attached to an engine and operated by a common form of reducing motion known as a *Brumbo pulley.* It consists of an arc fastened to a lever swinging about a fixed pivot and connected at the lower end to the crosshead.

For the pencil point graphite was formerly used and the diagram was traced on a piece of ordinary white paper, but at present almost all indicators have points of soft brass, a metal which makes a clear black line on paper coated with a starch sizing containing a chemical salt, usually zinc oxide. This paper has a hard, smooth surface, and will receive a mark from any soft metal, such as copper, lead, or aluminum. Sheets of it cut to the proper size and known as *metallic indicator cards* are sold in convenient blocks of 100, with blank forms for data printed on the back. Their use is generally advisable, for the brass pencil can be sharpened to a fine, rounded point which will glide over the paper with very little friction and remain sharp much longer than graphite.

When a diagram is to be taken from an engine, a card is wrapped about the drum and held by slipping its ends under the paper clips. The cord is then connected to the reducing motion and the indicator cock opened, admitting steam. Then the handle *22*, Fig. 2, is grasped and the sleeve *X* is turned, carrying the entire pencil mechanism and pressing the pencil against the paper.

As the pencil rises and falls the paper moves horizontally under it, and the two motions combine to produce an irregular figure known as the *indicator diagram.*

Hypothetical Diagram. Consider the diagram which would be drawn by the indicator at the head end of Fig. 3. When the piston is at the head end dead-point the cord is wound upon the drum. Motion toward the right pulls the cord, and if the indicator is like Figs. 1 or 2 the drum turns clockwise, as seen from above, moving the paper so that the pencil is in contact with the

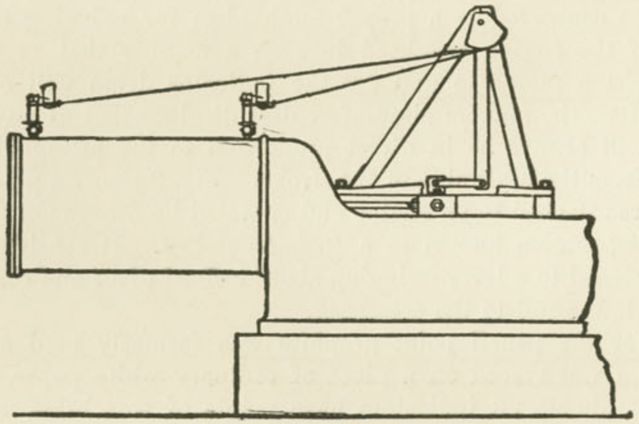


Fig. 3

right-hand end of the sheet when the piston reaches its crank-end dead-point. Suppose the engine admits steam just as its stroke begins, cuts off the supply at 39 per cent of the stroke, opens the exhaust valve at the end of the stroke, and shuts it for compression a little before the return stroke is finished. Suppose also that the act of opening or closing a valve is practically instantaneous, and that the steam ports are large enough to cause no perceptible loss of pressure in steam passing through. Assuming that the boiler pressure is 90 pounds per square inch and the pressure in the exhaust system is 7 pounds, and that a 60-pound spring is used in the indicator, the diagram drawn would be like Fig. 4.

The *atmospheric line g* is drawn by touching the pencil to the card before opening the indicator cock, and consequently shows

the height of the pencil when atmospheric pressure exists above and below the indicator piston. Pressures are usually measured from this line, although what are called absolute pressures are measured from another line, to be explained later. When the indicator cock is open, as soon as steam enters the engine cylinder the pencil rises to *a,* at a height corresponding to 90 pounds pressure per square inch. A scale divided into as many parts per inch as the scale of the spring, in this case 60, can be used to read pressures directly in pounds per square inch. As the engine piston moves toward the right, the paper *actually* moves to the left, but the *relative* motion is the same as if the paper were sta-

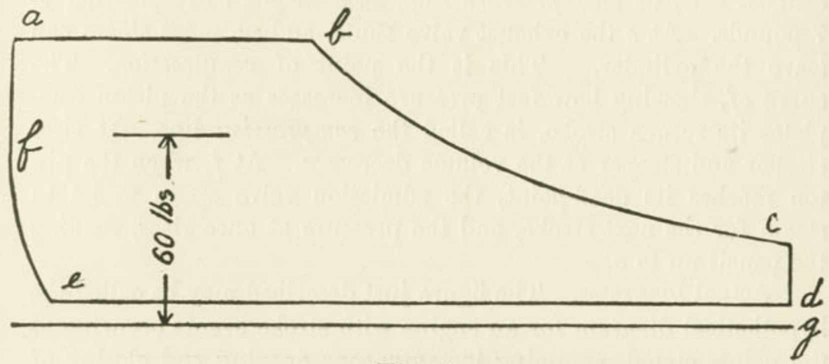


Fig. 4

tionary and the pencil moved toward the right. While steam enters the cylinder full pressure is maintained, as shown by the horizontal *admission line ab,* sometimes called the *steam line.* At *b,* cut-off takes place, after which no more steam can enter. What is already there at once begins to expand or increase in volume, and consequently decreases in pressure as the piston moves further on its stroke, thereby providing more room for the steam. The rate at which pressure falls off as volume increases is shown by the slope of the curve *b c,* called the *expansion line.* Notice that at first the drop is very rapid, and that it becomes less and less so as the pressure decreases. Point *c* marks the event of *release;* at that instant the exhaust valve opens, and since the pressure inside the cylinder is higher than in the exhaust pipe, a sudden rush of steam from the cylinder results, thus dropping the pressure to *d*. It is this sudden reduction in pressure at exhaust that causes the loud puffing of locomotives when operated with a late cut-off, and consequently high pressure at release. It also causes the still more noisy action of gas and gasoline engines when exhausting directly into the atmosphere without a muffler. Exhaust into a closed pipe, such as we have supposed, of course produces very little sound, no matter how great the drop in pressure.

During the return stroke the piston pushes the remaining steam out through the exhaust port, but does not thereby increase the pressure, for the port is assumed to be large enough to offer no obstruction. During this stroke the indicator traces *d e,* the *exhaust line,* or *back-pressure line,* at a height corresponding to 7 pounds. At *e* the exhaust valve shuts, and no more steam can leave the cylinder. This is the point of *compression.* The curve *ef,* showing how fast pressure increases as the piston completes its return stroke, is called the *compression line.* It rises steeper and steeper as the volume decreases. At *f,* when the piston reaches its dead-point, the admission valve opens to let in steam for the next stroke, and the pressure at once rises, sending the pencil up to *a*.

Actual Diagrams. The figure just described may be called the hypothetical diagram for an engine with stroke events occuring at the points stated, assuming instantaneous opening and closing of valves and no loss of pressure due to narrow steam ports. But the ports of actual engines are never large enough to offer absolutely no resistance to the flow of steam, and the valves open and shut *gradually,* so that the narrow crack they offer for passage when beginning to open or when almost closed increases the obstruction. The effect is to reduce the pressure by an action called *wire-drawing.* This always takes place when an elastic fluid is forced rapidly through a constricted passage. Suppose an engine has exceedingly small admission ports, and that it runs at high speed. When the stroke begins the piston moves outward, increasing the volume that steam can occupy. To maintain constant pressure behind it and draw a horizontal line like *a b,* Fig. 4, steam must enter the cylinder. Therefore the pressure in the steam chest must be higher than in the cylinder; otherwise no steam could pass through the port, for a body cannot start moving unless some unbalanced force or difference in pressure pushes it. If the piston moved

uniformly the required difference would be constant, and *a b* would be horizontal a little below the height corresponding to steam-chest pressure. But the piston velocity increases as the stroke proceeds, and to maintain constant pressure steam would have to enter the cylinder faster and faster, which it could not do unless the chest pressure increased so as to gradually increase the unbalanced force available for sending steam through the port in increasing quantity. Of course no such variation in steam-chest pressure can be arranged; at best this pressure can only be prevented from decreasing, and the inevitable result is that for a simple engine a constant pressure during admission cannot be maintained, but the line *a b* must slope downward. Its departure

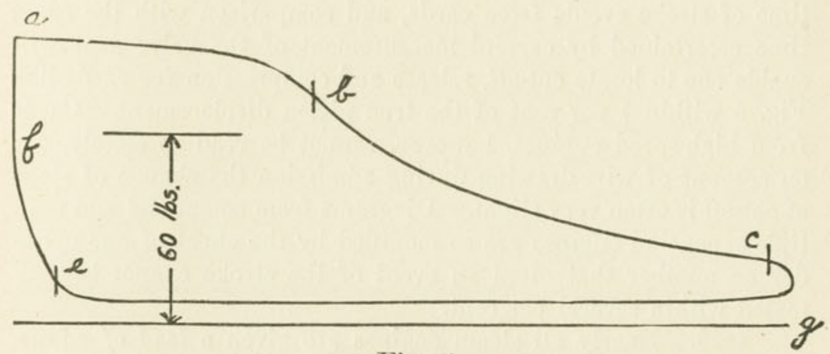


Fig. 5

from the horizontal becomes more noticeable as the engine speed increases.

If the admission valve remained wide open until just the moment for cutting off, and then closed instantaneously, a sharp turn in the indicator card would be produced as at *b,* Fig. 4; but in the actual case, while the valve is closing it gradually narrows up the steam passage, thereby further obstructing the flow, so that pressure decreases and rounds off the corner of the diagram, as shown in Fig. 5.

Fig. 5. is a typical diagram from an engine which runs at comparatively low speed, and which has its steam distribution clearly defined. It shows only a slight loss of pressure, due to *wire-drawing* in the port during admission, because the speed of such engines is always low, and ample port area is easily provided.

The admission valve is closed rapidly, though not instantaneously, by action of a vacuum dash-pot, so that the steam line is slightly rounded near cut-off. If the dash-pot is sluggish in its action, this rounding may become more noticeable. The exact point of cut-off is at *b*. It is around the bend of the admission line where the curvature reverses from concave on the lower side to concave on the upper. After the valve shuts no steam can enter or leave the cylinder until release at *c;* hence the quantity present expands and draws a curve whose general character does not change from cut-off to release. No sudden change in slope of this curve can occur until steam begins to leave the cylinder. When interpreting an indicator card a beginner is likely to place the cut-off too early and the release too late. A little practice in estimating the time of stroke events from cards, and comparison with the exact time ascertained by careful measurement of the valve gear will enable one to locate cut-off, release and compression for cards like Fig. 5 within 1 per cent of the true piston displacement. Cards from high-speed engines, however, cannot be read so closely, for on account of wire-drawing during admission the change of slope at cut-off is often very slight. Diagrams from compound and multiple-expansion engines are so modified by the effect of one cylinder on another that often an event of the stroke cannot be estimated within several per cent.

Lead. Nearly all steam engines are given a *lead of admission;* that is, the valve begins to open to let in steam just before the stroke begins. This is done to avoid excessive wire-drawing through the opening port during the first part of the stroke. The *lead* is the linear distance a valve has opened by the time the dead-point is reached, and for engines running at high speed it is often considerable, say ⅜ inch for an engine with only 3 inches valve travel. It might seem that to get such a lead a valve must begin to open so long before the dead-point that high pressure would be let into the cylinder too soon, and so oppose the piston just then completing its return stroke. But such is not the case. When the crank is approaching its dead-point, and the piston coming to rest, the valve is not far from mid-position and is still moving rapidly, so that to get a considerable lead it is not necessary to begin opening the valve much before the piston has finished its return stroke. In the engine from which Fig. 5 was taken the valve had ⅛ inch lead, and steam began to enter the

cylinder while the crank was still several degrees from its dead-point, but the piston had so nearly reached its end position, and the indicator card was so nearly at rest that the diagram gives no evidence of just when the valve opened or just what maximum pressure was developed in the cylinder by compression. A method of obtaining this information will be described later.

If there is no lead, instead of rising vertically from *f*, Fig. 5, the diagram will slope toward the right as in Fig. 9. This prevents full pressure acting on the piston till after the working stroke has begun, and so decreases the power of the engine.

Release takes place before the stroke is finished, and the card, Fig. 5, shows consequently a slight loss in driving force just at the end of the stroke; but this setting is necessary to get the exhaust

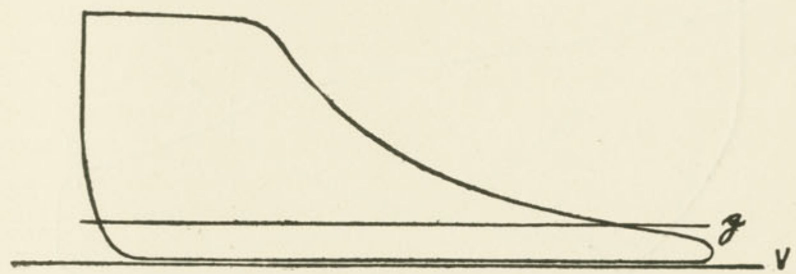


Fig. 6

valve wide open when the return stroke begins, and thus give a clear passage for steam leaving the cylinder.

Stroke events are always measured from the admission end of the stroke, and are stated in inches of piston displacement or in per cent of full stroke. The latter can be measured from the card without knowledge of the actual piston stroke, but for the former the length of stroke must be known. Thus the diagram, Fig. 5, taken from a simple engine, shows a cut-off at 39 per cent, which corresponds to a piston displacement of 16⅜ inches; release at 96 per cent and compression at 5 per cent. This valve setting may be considered a very good one for a simple, non-condensing engine.

If the engine exhausts to a condenser the diagram drawn will lie partly above and partly below the atmospheric line, as shown clearly in Fig. 6. Pressures may still be measured from the atmospheric line, being called positive when above and negative below, or they may be measured from the *vacuum line, V*, drawn below the atmospheric line at a distance corresponding to barometric pressure when the card was taken. No part of the diagram can fall below this line, for it represents the absolute zero of pressure as nearly as can be produced. All pressures measured from it are necessarily positive, and the confusion often arising in computations involving negative signs is thus easily avoided. Atmospheric pressure varies with the weather, and also with the altitude. Near sea-level the barometer seldom rises above 31 inches, or falls below 29 inches, averaging about 30 inches. A column of mercury 1 inch high exerts a pressure of .491 pounds per square inch, so that the pressure of the atmos-

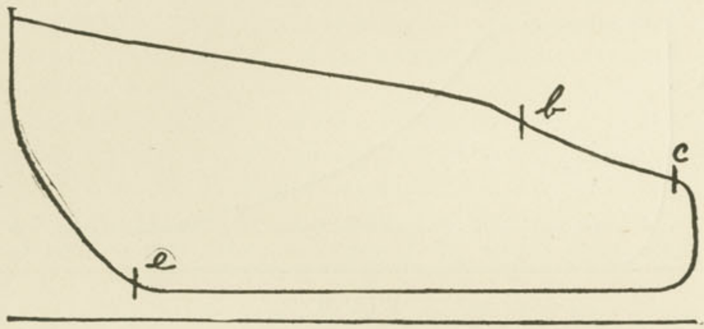


Fig. 7

phere corresponding to the mean barometric height is 30x.491, or 14.7 pounds per square inch. Often the approximate figure 15 is close enough, and the vacuum line may be drawn 15 pounds below the atmospheric line. If, however, greater accuracy is desired, for instance on a card from a low-pressure cylinder where the whole diagram is below the atmospheric line, where the maximum range in pressure is perhaps only 8 or 10 pounds, and where the use of a sensitive spring in the indicator permits greater precision of measurement, then the barometer reading should be obtained and the true atmospheric pressure calculated.

Fig. 7 is the typical diagram from a slide-valve engine, with fixed eccentric, such as is used for driving centrifugal blowers, for hoisting and for other purposes requiring comparatively small

power and not the best economy. As the speed of such engines is usually high, a considerable loss in pressure takes place during admission. The steam line is always rounded by further wire-drawing while the valve is closing, so that accurate location of the cut-off is more difficult than for the card of a Corliss engine. Cut-off is usually after half-stroke, often as late as $\frac{2}{3}$ or $\frac{3}{4}$ stroke, so there is comparatively little expansion, and when release occurs the pressure within the cylinder is still much higher than that into which it exhausts; in other words, the expansion is very incomplete. Slide-valves, when designed and set to cut-off before half-stroke, necessarily give early compression or late release. They are seldom used for early cut-off, except in connection with

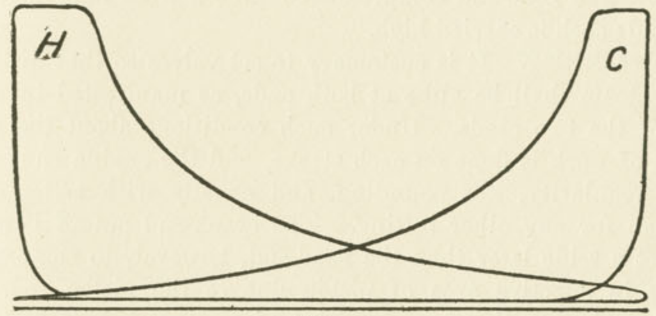


Fig. 8

some variable expansion gear, such as a Stephenson-link or a fly-wheel governor.

Diagrams from the head and crank-ends of an engine cylinder may be taken with separate indicators, as in Fig. 3, or a three-way cock may be used to connect a single indicator with either end, so that both diagrams may be taken on the same card, one after the other, as in Fig. 26.

Fig. 8 shows a pair of diagrams from a slow speed engine running at only 48 revolutions per minute. The pressure at the throttle was 85 pounds, and the engine exhausted through a coil feed-water heater to an open exhaust head on the roof of the building. The *mean exhaust pressure,* or the average pressure in the cylinder during either exhaust stroke, was a trifle more than 2 pounds, caused by resistance to passage of steam through the heater, as well as the exhaust ports and pipes. Head and crank-end cards are marked H and C. This engine has drop cut-off valves actuated by springs which shut the valves quickly, as shown by the comparatively sharp corners on both diagrams. No perceptible loss of pressure is shown during admission to either end. This is due to low speed and ample port area. The head cut-off is slightly longer than the crank. Both are very early—so early that expansion is nearly complete; that is to say, the steam expands till its pressure is reduced to nearly that in the exhaust pipe before it is released. The two back-pressure lines coincide exactly for most of their length, as of course they should, for both ends of the cylinder exhaust into the same pipe, and as each sends out approximately the same amount of steam it should meet with the same resistance to passage. The head-end compression begins a trifle later than the crank-end; each is carried high.

Valve Setting. It is customary to set valves so that distribution of steam shall be alike at both ends, as manifested by similarity of the two cards. Under such conditions about the same amount of work is done on each stroke, and the engine runs with greater regularity, less pounding, and usually with better economy than for any other setting. The crank-end cut-off is sometimes set a trifle later than the head-end, however, to compensate for loss in effective area of piston due to the piston rod. In vertical engines a difference in point of compression is desirable to counteract the weight of the piston and crosshead. The most desirable setting for engine valves depends on the type of engine, its speed, and the conditions of service under which it operates. In general:

1. Only enough lead should be given to produce perpendicular lines on the indicator diagrams at the beginning of admission.

2. The port opening should be enough to prevent excessive loss of pressure by wire-drawing during admission.

3. Cut-off should be at approximately the same per cent. of the stroke at each end and should be as rapid as the nature of the gear will permit. In drop cut-off gears the dash-pots should act promptly.

4. Release should occur no earlier than absolutely necessary to insure a quick drop to back pressure and prevent undue loss of power by impeding the piston at the beginning of its exhaust stroke.

5. Compression should occur early enough to cushion the reciprocating parts and also to raise the steam pressure well up toward boiler pressure. This last requirment is essential for good economy in the use of steam.

Fig. 9 shows a pair of cards from a horizontal engine with slide valve and fixed eccentric. The valve gear was known to be improperly adjusted, and these two diagrams were taken to discover wherein lay the error. (Arrows have been supplied and the points of cut-off marked to aid the reader in distinguishing head and crank-end cards.) The most serious fault shown is an extremely late admission at each end. Not only do the lines depart from perpendiculars, but they do not rise at all till after the stroke is well begun. Both points of cut-off are very late—too late even for a slide valve. There is almost no expansion. Both ends release so late that considerable pressure remains in the cylinder for some time after the return stroke begins, thus reducing the power. There is no compression at either end. To

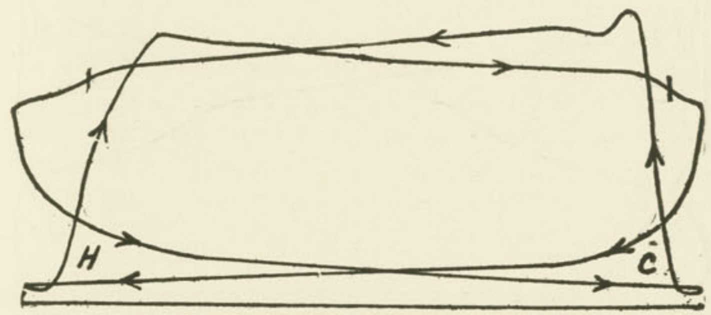


Fig. 9

be sure the port is finally shut, after which no more steam can leave the cylinder, and such closing is always defined as the event of compression, but in this engine the return stroke is completed and the forward stroke begun when closure takes place. All eight valve events, four at each end, are therefore too late, which means that the eccentric was not set far enough ahead of the crank. Accordingly it was advanced about 15°, and the next cards taken looked like Fig. 10. Here a vibration of the pencil mechanism due to sudden change of pressure at admission produced a wavy line at the top of each card. This action is often unavoidable, even with the best indicators. A stiff spring will sometimes reduce but not entirely prevent it. Fortunately it is of no serious consequence, for a line can be sketched through the undulations which will represent very closely the true changes in pressure and volume as shown dotted on the head-end card. But this line will *not* pass through points half way between crest and trough of each wave. It should pass nearer the first trough than the first crest, nearer the second crest than the first trough, and so on, for after a spring has received a sudden blow, the amplitude of its vibrations above and below a median line gradually diminishes as it comes to rest.

The cards of Fig. 10 show that the head-end admission is now early enough, and the crank-end still a little late, though not seriously. Head-end cut-off is later than crank-end. Head-end release is later than crank-end. Head-end compression is earlier than crank-end. Therefore the adjustment might have been

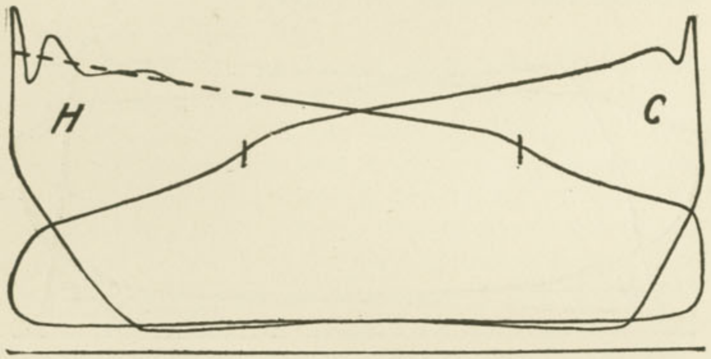


Fig. 10

further improved by slightly lengthening the valve spindle, for the engine had a slide valve admitting steam at the outside edges, so that lengthening the spindle would have hastened cut-off, hastened release, delayed compression and delayed admission at the head-end, and produced opposite effects at the crank-end. But the diagrams as they stand in Fig. 10 show very good steam distribution, and little would have been gained by changing it.

The cards of Fig. 9 are not nearly as bad as would be drawn by many engines actually running, if the owners would take the trouble to indicate them. To show that the faults detected by such cards are of serious consequence, and lie not merely in the looks of the diagram, it may be stated that in the engine from which Figs. 9 and 10 were taken the change in valve adjustment, besides

stopping a very objectionable pounding at the crank pin, cut down the steam consumption from 43.1 pounds to 34.6 pounds per horse-power per hour.

Fig. 11 shows the effect of excessive angular advance. All the events are too early. Steam is released and allowed to escape long before its work is finished, and compression occurs so early that the pressure developed rises high above that in the steam chest. At *f* the admission valve opens, but instead of steam entering the cylinder from the chest, it momentarily goes the other way until the pressures are equalized. Such excessive cushion-

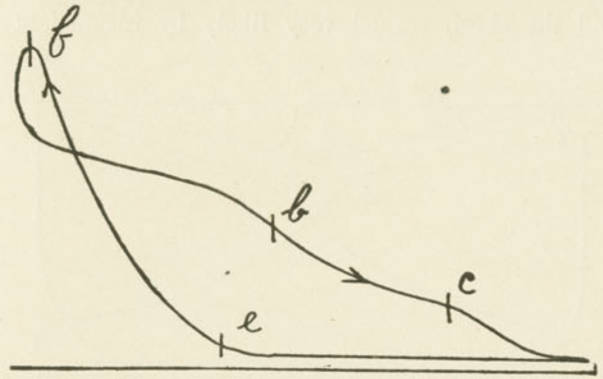


Fig. 11

ing is not necessary for quiet running, even at highest speed. It reduces the power, for the loop in the diagram shows that during the last part of the return stroke, when the piston should be impeded as little as may be, the resisting force is even greater than that exerted to drive the piston over the same part of its travel during the working stroke. To cite a case illustrating the loss due to such valve adjustment, a horizontal engine 8 inches diameter by 10 inches stroke, direct-connected to a centrifugal pump, had its speed increased from 156 revolutions per minute to 215 r. p. m. by merely setting the eccentric back to its proper position, as shown by the indicator.

In case of excessive wire-drawing during admission or exhaust, the indicator may be used to determine whether it is caused by a small steam pipe or narrow cylinder ports. For this purpose an indicator may be connected to the steam-chest and simultaneous diagrams taken from the chest and the cylinder. The chest diagram may then be transferred to the cylinder card, when the combination will look like Fig. 12. Though two diagrams are obtained from the cylinder, only one is drawn from the steam-chest. It is *i e f h g f i*. The admission lines *a b* and *c d* slope rapidly, proving that an obstruction or constriction exists somewhere between the boiler and the cylinder. Line *i e* slopes downward, though not so fast as *a b*, showing that the steam-chest pressure decreased while the head-end was taking steam, and that a further drop occurred before steam got past the valve into the cylinder. This indicates too great resistance to flow between the boiler and the chest, caused very likely by insufficient opening

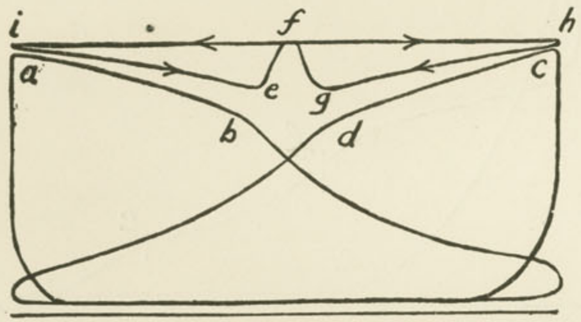


Fig. 12

at the throttle, though possibly by too small a steam pipe. The drop between *i e* and *a b* is attributable only to a small port or incomplete opening of the port by the valve. When the valve shuts at *b*, the chest pressure rises from *e* to *f*, and remains constant to the end of the stroke *h*, for during this period no steam passes through the chest. At *h*, steam begins to enter the crank-end, and the drop *h g* occurs. If *i e* had been more nearly horizontal, it would have shown less wire-drawing in the throttle or the pipe and more in the cylinder port. Cards from engines with throttle governors, running at light load, often have *i e* and *h g* sloping more than in Fig. 12, the loss in pressure being caused by intentional wire-drawing at the governor. Cards from engines with shaft governors at light load have *i e* nearly horizontal and *a b* dropping rapidly below, the greater loss in pressure occurring in the cylinder ports, due to reduction in port opening which the

governor introduces in hastening the cut-off to suit a lightened load.

In a given interval of time the crank of an engine turns through equal angles, beginning at any point of its revolution. Its motion is uniform. That of the piston is not uniform. Near the dead points it travels very slowly, and since the indicator drum is turned proportionally to the piston motion, the card produced is shortened at the ends, so to speak, a given horizontal distance near either end representing much longer duration than the same distance measured at the middle. In Fig. 5, the compression line rises steeper as the volume decreases, and becomes perpendicular apparently at the dead point. The time elapsing while pressure increases from *f* to *a* cannot be estimated from this card, because *f a* is practically a straight, vertical line, yet we know that this

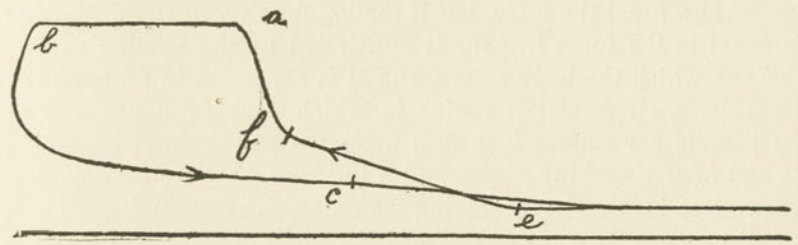


Fig. 13

rise in pressure can not be instantaneous. To lengthen out the ends of a diagram for the purpose of studying how the pressure changes, we may pull the indicator cord uniformly, by a drum geared from the engine shaft, and then shut the cock before letting it re-coil; or we may take what is called an *eccentric card* by attaching the cord to the valve rod or some other part of the valve gear instead of to a reducing motion connected with the crosshead. Events occurring near the ends of an ordinary card will be transferred to the middle of this new diagram because the motion is derived from the eccentric, which, roughly speaking, is somewhere near mid-position when the piston is near its dead-points. Fig 13 is an eccentric card from a Corliss engine similar to that from which Fig. 5 was taken, except that the cut-off occurred earlier and there was not quite so much compression. It was taken by connecting the indicator cord to the rocker between the eccentric-rod and the gab-rod or wrist-plate rod. From the nature of the motion, therefore, equal horizontal distances do not represent equal intervals of time, but the diagram is nevertheless useful for determining the pressure existing at the end of compression. Corresponding events on Figs. 13 and 5 are lettered alike. The change in pressure occurring at the end of compression is shown very clearly in 13, point *f* indicating the moment of opening to admit steam from the boiler. The slope of *f a* shows an appreciable time elapsing before maximum pressure is reached, though it cannot easily be used to *measure* the time.

INDICATED HORSE-POWER.

Work is done whenever a force acting upon a body moves it through space. If the body does not move, no work is done, regardless of how great the force, but if motion does result the work done is equal to the force in pounds multiplied by the number of feet through which the body moves, and it is expressed in *foot-pounds.* Consider a single-acting engine in which a uniform pressure of 90 pounds per square inch acts upon the piston from beginning to end of the working stroke, and a uniform pressure of 7 pounds per square inch resists it during the entire exhaust stroke. These conditions are the same as assumed for Fig. 4, except that steam is not cut off till the stroke is finished and there is no compression whatever. If the piston area is 95 square inches, and the stroke is 18 inches, or 1.5 feet, the total force acting during the working stroke is 95x90, or 8,550 pounds, and the work done upon the piston is 8,550x1.5, or 12,825 foot-pounds. During the return stroke steam pressure on the piston cannot assist, but can only impede its motion. The piston is driven back by the crank and fly-wheel against a total pressure of 95x7, or 665 pounds, and the work thus done *by* the engine *on* the steam in pushing it out of the cylinder is 665x1.5, or 997.5 foot-pounds. The net result is that 12,825—997.5, or 11,827.5 foot-pounds are done by the steam each revolution. At 200 revolutions per minute the steam would do work at the rate of 200x11,827.5, or 2,365,000 foot-pounds per minute, and this would be the *power* developed, for *power* expresses the *rate of doing work.*

Smaller numbers being desirable, a larger unit than 1 foot-pound per minute is used, viz.: the *horse-power* consisting of 33,000 foot-pounds per minute.* The power developed by steam in the engine here considered would therefore be

$$\frac{2,365,000}{33,000}, \text{ or } 71.7 \text{ horse-power.}$$

Reviewing the method by which this result is obtained, we may write the algebraic formula

$$\text{I.H.P}=[(\text{P}\times\text{A}\times\text{L})-(p\times\text{A}\times\text{L})]\times\frac{\text{R.p.m.}}{33,000}$$

where *I.H.P.* stands for indicated horse power; *A* for area of piston in square inches; *P* for pressure per square inch during the working stroke; *p* for pressure per square inch during the exhaust stroke; *L* for length of stroke in feet; *R.p.m* for revolutions per minute. Simplifying,

$$\text{I.H.P}=\frac{(\text{P}-p)\times\text{A}\times\text{L}\times\text{R.p.m.}}{33,000}$$

in which *P—p* shows the difference in pressure per square inch during the two strokes. The indicator diagram drawn by such an engine would be a rectangle in which *P—p* would appear as the height of the diagram, and might be measured directly in pounds by applying the proper scale.

Now suppose that as in the actual case the engine is not supplied at constant pressure throughout the driving stroke, but that from the beginning, steam pressure gradually decreases, due to wire-drawing, that cut-off occurs, followed by expansion and loss of pressure, and that the return stroke terminates with a sudden rise due to compression. The card would then be like Fig. 5. For computing the horse-power developed we can no

*James Watt selected this value. He knew that it represented a faster rate of working than a horse can maintain for any considerable time, but he was building steam engines and installing them in competition with animal power, and on business principles he preferred to underrate rather than over rate his machines.

longer determine *P* or *p* by a single measurement, since neither is constant from end to end; but we can take mean values of *P* and *p*, separately, by measuring the pressure at a number of equidistant points, and then averaging, or we can obtain more directly a mean value of the *difference, P—p,* by averaging the height from back pressure line to steam line, measured in a number of places. By the former method we should be finding *P*, the average pressure acting during the forward stroke upon each square inch, a pressure which, if exerted uniformly throughout the stroke, would *give to* the piston just as much work as is actually given by the varying pressure; and we should be finding *p*, the average pressure resisting the piston on its return, a pressure which, if exerted uniformly throughout the stroke, would *take from* the piston exactly as much work as is taken by the varying back pressure. Subtracting this mean resisting pressure from the mean driving pressure, we get the *mean effective pressure,* a force which, if exerted constantly on each square inch of the piston from beginning to end of the working stroke and then ceasing entirely during the return stroke, would do the work actually done by the varying pressures during a complete revolution.

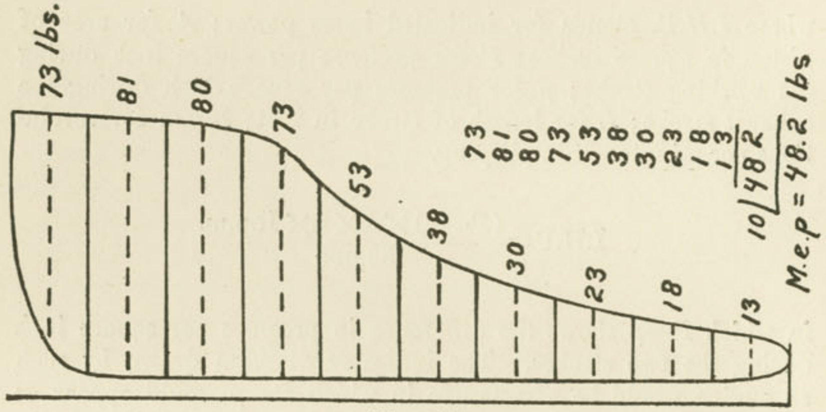


Fig. 14

The second method is shorter. The mean value of *P—p,* the mean effective pressure, is simply the average vertical height of the steam line above the back-pressure line expressed in pounds per square inch instead of in inches. Figs. 14, 15, and 16 show

how it can be measured. Each card is divided into 10 vertical sections of equal width, and the middle height of each strip, shown by a dotted line, is measured to the proper scale of the indicator spring. The average of these 10 measurements is the mean effective pressure. In any looped diagram showing lower pressure during a part of the driving stroke than during the corresponding part of the return stroke, the middle heights of strips in the looped parts must be given negative signs and allowed for in averaging. Cards like Fig. 16 are often very confusing. The first step toward correctly understanding such a diagram is to ascertain in which direction the line was traced, and to identify the points of cut-off, compression, etc., so that the steam and expansion lines may be distinguished from the back-pressure line.

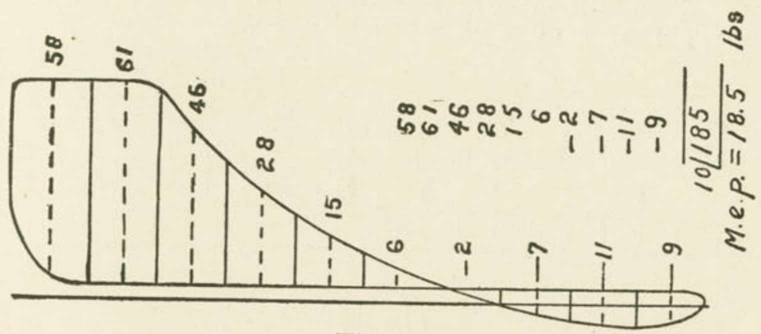


Fig. 15

At speeds above 250 it is difficult to tell by watching the indicator which way the pencil draws the diagram, but this can usually be determined by studying the card itself. In Fig. 16, *d* is easily identified as the point of compression, from which it is at once apparent that the card was traced as indicated by the arrows. In the enclosed part lettered *a e d f* the expansion line *a e* is higher than the back-pressure line, which means that this part represents positive work done by the steam on the piston. But in the two loops *e b c* and *f g h* the reverse is true, signifying that the work represented by these areas is done by the piston on the steam, and consequently is of negative value. The sum of the negative pressures is greater than the positive, so the average or mean effective pressure must be written with a negative sign. This means that the horse-power calculated from such a diagram will be negative. The piston actually pumps steam out of this end of the cylinder instead of itself being driven by the steam. This card is a light load diagram from the low-pressure cylinder of a compound engine with fixed eccentric for the low and a shaft governor for the high-pressure valve. The engine was designed to run condensing, but was operated non-condensing, hence the exhaust line *c e d* is much higher than it should be. If exhausting to a condenser the loop *e b c* would disappear, and probably *f g h* would be scarcely perceptible. As it was, the high-pressure

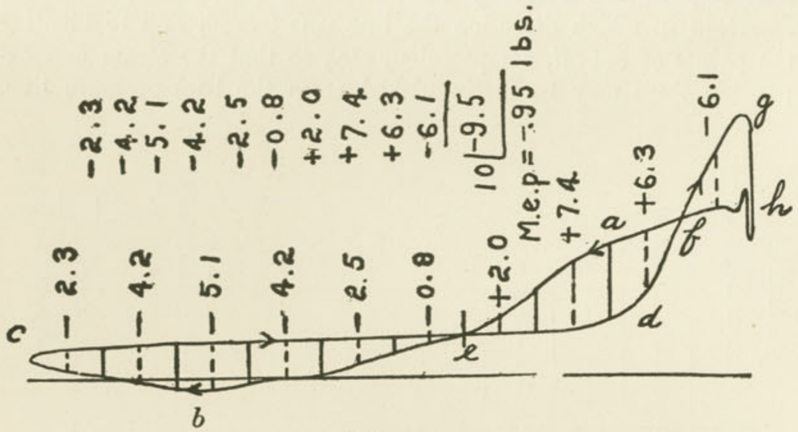


Fig. 16

cylinder dragged the low like a pump, and the total indicated horse-power of the engine was less than that of the high alone.

Instead of obtaining the mean height by averaging a number of measurements, we can make use of the fact that the average vertical height of any figure equals its area divided by its horizontal length. The average height of an indicator diagram from back-pressure line to steam-line is equal to the area in square inches divided by the length in inches.

The Planimeter. An instrument for obtaining areas of plane figures bounded by irregular lines is shown in Fig. 17. It is called a planimeter. For use it is laid on a table and placed about as shown with reference to the diagram whose area is to be found. The *polar* arm *AB* turns about the pivot *A*, which is depressed into the table and held in place by a weight. The *tracing* arm *BC* is hinged to the polar arm at *B*, and carries a tracing point *C*, a recording wheel *D*, and a vernier *E*. The instrument touches the table at only three points—*A*, *C*, and the bottom of the recording wheel. The axis of the wheel is exactly parallel to the table and in line with *B C*, or, as sometimes made, parallel to *B C*. It turns with very little friction. Its disc is of hardened steel, with a V-shaped edge ground to exact diameter. Attached to it is a cylindrical scale *D*, divided into 10 equal parts, each subdivided into 10. The vernier does not turn with the wheel, but is carried on the tracing arm. It has 10 equal divisions, covering 9 of those on the wheel, thus serving to read the distance through which the wheel turns to $\frac{1}{10}$ of a division, or $\frac{1}{1000}$ of its

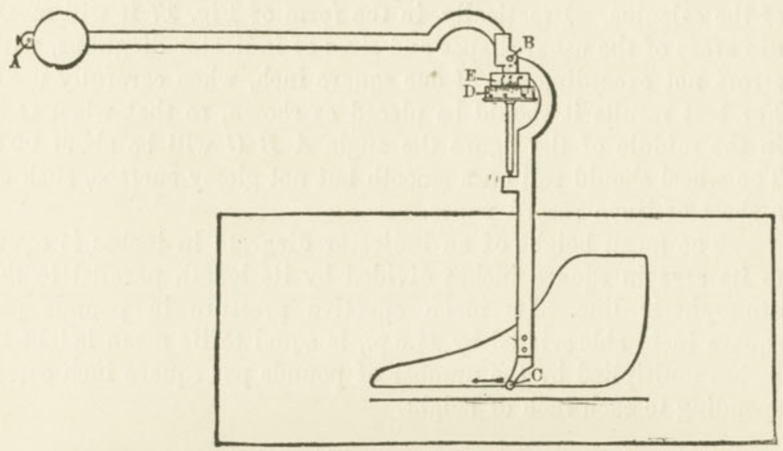


Fig. 17

entire circumference. If the tracing point is moved say to the left for a short distance, the wheel rolls so that its reading against the vernier zero increases. Then if the tracing point is returned *along the same line* to its original position, the wheel rolls backward until it reads exactly as at first. But if *C* is traced around any line enclosing an area, in the direction of the hands of a clock, the wheel rolls so that its readings now increase, now decrease, in apparently erratic fashion, yet when *C* finally reaches its starting-point the reading is greater than at first, and the difference is a measure of what may be called the *travel of the wheel*, or its final circumferential displacement past the vernier zero. The remarkable property of this instrument is that the area in square inches of the figure traced is equal to the *travel of the wheel* in inches multiplied by the length of the tracing arm. The planimeter shown in Fig. 17 is of convenient size and made especially for indicator cards. The diameter of the wheel is .7458 inches, its circumference 2.343 inches, and the length of the tracing arm 4.27 inches. $2.343 \times 4.27 = 10.00$. Therefore one complete revolution of its wheel records 10 square inches, and the scale is so divided. If the scale reading before starting around a card is 4.89, and after finishing 6.97, the area is equal to the difference, or 2.08 square inches. Usually it is well to set the scale at zero when starting. The final reading then gives the area. In principle the planimeter is mathematically correct, as can be demonstrated by means of the calculus. Practically, in the form of Fig. 17 it will measure areas of the usual shapes and sizes of indicator diagrams, with errors not exceeding $\frac{1}{100}$ of one square inch, when carefully used. For best results it should be placed as shown, so that when *C* is in the middle of the figure the angle *A B C* will be about 90°. The wheel should roll on a smooth but not glossy surface, such as a sheet of linen record paper.

The mean height of an indicator diagram in inches is equal to its area in square inches divided by its length parallel to the atmospheric line. Its mean effective pressure in pounds per square inch, abbreviated by M.e.p., is equal to its mean height in inches multiplied by the number of pounds per square inch corresponding to each inch of height.

$$\text{M.e.p} = \frac{\text{Area of diagram}}{\text{Length}} \times \text{Scale of spring.}$$

In planimetering a looped diagram, that part which represents positive work should be traced clockwise, in order that the area shall read positive. Start at any point on this part of the diagram, for example at *a,* Fig. 16, and move in a clockwise direction, but instead of tracing each loop separately follow the diagram continuously, thus: *a f h g d e c b e a.* In so doing the loops *f g h* and *e b c,* representing negative work, will be traced in a counter-clockwise direction, and the planimeter will automatically subtract the sum of their areas from that of *e d f a,* so that a final reading will show the net area of the card. If, as in Fig. 16, the two negative areas together exceed the positive, the

planimeter, if started at 0 or 10, will finally read less than 10, and the difference should be given a negative sign. Let it be understood, however, there can be no such thing as a negative area, or a negative pressure exerted by a fluid; but the area of an indicator card and its mean effective pressure may be written with minus signs to show that power calculated from them is to be subtracted when finding the total power of the engine.

Position of the atmospheric line has no connection with the mean effective pressure. A card may be entirely above it, as in Fig. 14, part above and part below, as in Fig. 15, or entirely below, as in cards from the low-pressure cylinders of some triple-expansion engines, yet the M.e.p. may be obtained as described, with

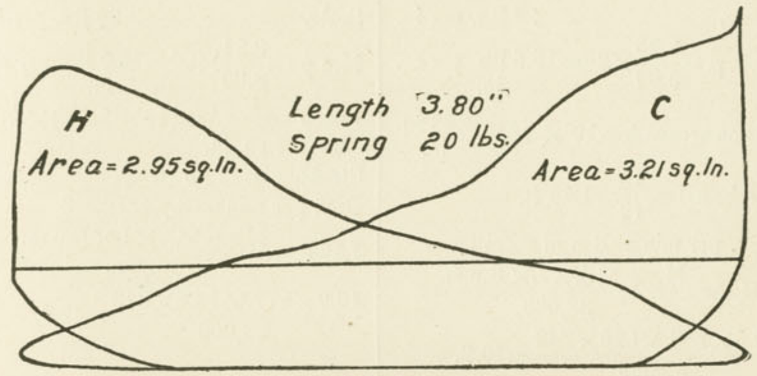


Fig. 18

no necessity for the atmospheric line except to show a direction parallel to which the length of the diagram should be measured.

Returning now to the calculation of power by means of the formula on page 739, and re-writing the formula in other symbols, the *indicated horse-power.*

$$\text{I.H.P} = \frac{\text{M.e.p} \times \text{A} \times \text{L} \times \text{R.p.m.}}{33{,}000}$$

This is the rate at which work is done by steam in one end of a cylinder. If, as is usually the case, the engine is double-acting, the powers for head and crank-ends are computed independently and then added. The indicated horse-power is usually from 6 to 10 per cent greater than the brake horse-power or work available at the shaft, for part of the work done by steam is wasted in friction of the engine.

The diagrams of Fig. 18 are from the low-pressure cylinder of a compound condensing engine running at 242 revolutions per minute. The piston diameter is 19 inches and the stroke 15 inches. A piston-rod $2\frac{5}{8}$ inches in diameter passes through the crank-end cylinder cover. Areas were found by means of a planimeter. The indicated horse-power is computed as follows:

Head-End.

Area of diagram, 2.95 sq. in.
Length of " 3.80 in.
Scale, 20 lbs. per in.

$$\text{M. e. p.}=\frac{2.95}{3.80}\times 20=15.5 \text{ lbs. per sq. in.}$$

$$\text{Piston area}=A=19^2\times .785=283 \text{ sq. in.}$$

$$\text{Stroke}=L=\frac{15}{12}=1.25 \text{ ft.}$$

Rev. per min.=R.p.m.=242.

$$\text{I.H.P.}=\frac{\text{M.e.p.}\times A\times L\times \text{R.p.m.}}{33{,}000}=\frac{15.5\times 283.\times 1.25\times 242}{33{,}000}=40.2.$$

Crank-End.

Area of diagram, 3.21 sq. in.
Length of " 3.80 in.
Scale, 20 lbs. per in.

$$\text{M.e.p.}=\frac{3.21}{3.80}\times 20=16.9 \text{ lbs. per sq. in.}$$

$$\text{Piston area}=A=(19^2-2.62^2)\times .785=277 \text{ sq. in.}$$

Stroke=L=1.25 ft.

Rev. per min.=R.p.m.=242

$$\text{I.H.P.}=\frac{\text{M.e.p.}\times A\times L\times \text{R.p.m.}}{33{,}000}=\frac{16.9\times 277.\times 1.25\times 242}{33{,}000}=42.9.$$

Total indicated horse power of low-pressure cylinder=

$$40.2+42.9=83.1.$$

The power of the high-pressure cylinder would be calculated from its cards in the same manner, and the two added to give the total indicated power of the engine.

The effective piston area at the crank-end is less than at the head-end on account of the piston rod, and since one other factor of the *I.H.P.*, namely, the *M.e.p.*, is usually different for each end, separate computations for *I.H.P.* are repuired for strict accuracy. A practically correct value of the total power can, however, be obtained by a single computation, taking for *M.e.p* the sum of the two values found for head and crank cards, and for *A* the average piston area, as follows:

$$\text{Total I.H.P.}=\frac{(15.5+16.9)\times\frac{283+277}{2}\times 1.25\times 242}{33{,}000}=83.2$$

This method facilitates computation by logarithms or by the slide-rule, and is usually good enough, but it is not mathematically correct, and may lead to serious error if the mean effective pressures differ greatly and the piston rod is relatively large.

Computations of power, or in fact any calculations based on indicator data, should very seldom be carried out to more than three significant figures. The planimeter will not measure a diagram closer than 1 part in say 200, and the indicator itself, even in the hands of an expert and used under the very best conditions, will seldom draw its line within one per cent of the correct height. Under less favorable conditions the error may be much greater. Therefore the custom of reporting horse power or results depending on it to 4, 5, or even 6 places is a waste of time, and its apparent precision is likely to mislead.

The formula usually given for calculating power is

$$\text{I.H.P.}=\frac{P\times L\times A\times N}{33{,}000}$$

where P is the mean effective pressure per square inch, L the stroke in feet, A the area of the piston in square inches, and N the revolutions per minute. The numerator is easily remembered, since its factors spell the word *plan;* but the logical order is P×A×L×N, for a pressure per square inch times the area on which it acts gives the total force exerted, and this multiplied by the distance in feet,*L,* through which it acts, gives the work done on one side of the piston per revolution. Multiplication by the number of revolutions per minute and division by 33,000 then completes the calculation.

Two factors in the expression for I.H.P., viz.: M.e.p. and R.p.m., vary according to the conditions of operation. The other three, area of piston, length of stroke, and the value 33,000, are always constant, unless, of course, the cylinder is re-bored to larger diameter. For any given engine, therefore, it is convenient to find the value

$$\frac{A\times L}{33,000}$$

and use this *engine constant* or *horse power constant* in computing power. This constant is the indicated horse power developed per pound mean effective pressure per revolution per minute. For example, the head-end of a 10x14 inch engine has a horse-power constant of

$$\frac{(10^2\times .785)}{33,000}\times\frac{14}{12}=.00278.$$

The horse-power developed by an M.e.p. of 40.2 pounds at 196 R.p.m. would be $.00278\times 40.2\times 196=21.9$.

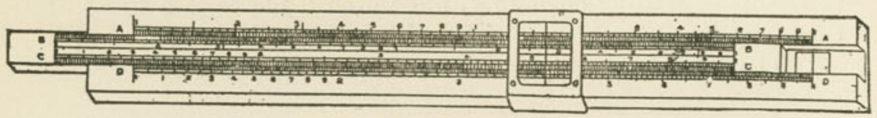


Fig. 19

The Slide Rule. Numerical problems involving multiplication and division only, such as the determination of mean effective pressures and the calculation of power, are very quickly solved on the *slide rule* shown in Fig. 19. This consists of the *rule A D,* usually about 10 inches long, the *slide B C,* and the *runner,* which carries a glass plate on which a fine index line is engraved. There are two sets of scales: *A* is exactly like *B,* and *C* like *D.* Calculations may be performed on either set, but greater accuracy is possible on the lower scales. The rule is divided proportionally to the logarithms of numbers; that is, on the *D* scale if the total length is 10 inches, and this distance is called equal to the log. of 10 or 1, then the distance from 1 to 2 is made equal to $10\times$log. 2, or 3.010 inches, and the distance from 1 to 3 is $10\times$ log. 3. To multiply 2 by 3 move the slide to the right till the left

end of the *C* scale coincides with 2 on the *D* scale, then opposite 3 on the *C* scale will be found the required product 6 on the *D* scale. The method depends only on the simple fact that the logarithm of a product is equal to the sum of the logarithms of its factors. Conversely, to divide 7 by 3, set 3 on the *C* scale opposite 7 on the *D* scale, and the left end of the slide will then be opposite the quotient 2.33+ on the *D* scale. The calculation of M.e.p. for the head-end card of Fig. 18 is performed with one setting of the slide, as follows: Opposite 295, or 2.95 of the *D* scale, set 380, or 3.80 of the *C* scale. This divides 295 by 380, and the fact that the left end of the slide is then off to the left of the rule shows that the quotient is less than 1. But to know this quotient is unnecessary; what is wanted is 20 times its value, so look along the slide till the mark 2 is found, and the result desired, 15.5, will be opposite it on the *D* scale. In using the rule no attention need be paid to the decimal point, for the

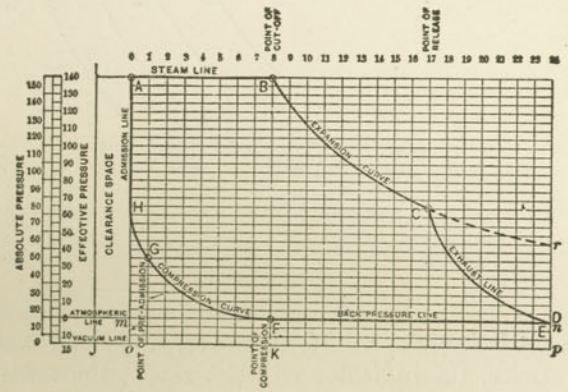


Fig. 20.

logarithms of numbers, having the same sequence of figures differ only by whole numbers, so that the sequence obtained as a result will not vary, and though such a computation does not indicate whether the M.e.p. is 1.55 or 15.5 or 155, the proper value is evident from inspection of the card. Ability to make rapid computations without using paper and pencil is often of great value to an engineer. The calculation just given, if performed by arithmetic, will require perhaps 40 seconds; by the slide rule it takes scarcely 8, and necessitates less mental effort. Complete solution of the fraction for I.H.P. for either card of Fig. 18 ought not take more than half a minute with the slide rule.

Fig. 20 represents a form of indicator diagram from a locomotive in which the steam is distributed by a link motion so as to produce the best practical action in the cylinders. The various events which take place in one end of the cylinder throughout one revolution are shown by the points A, B, C, D, F, G and H. An actual diagram taken from a locomotive, however, would not have the exact form as shown in Fig. 20, but the corners would be considerably more rounded and the different lines more wavy.

When the load against which an engine operates is steady and steam pressure at the throttle as well as the exhaust pressure does not vary, the cycle of changes for one revolution is just the same as for the next, and the indicator pencil will trace the same line over and over again as long as it is held against the paper. This is the case with marine engines, pumping engines, or engines

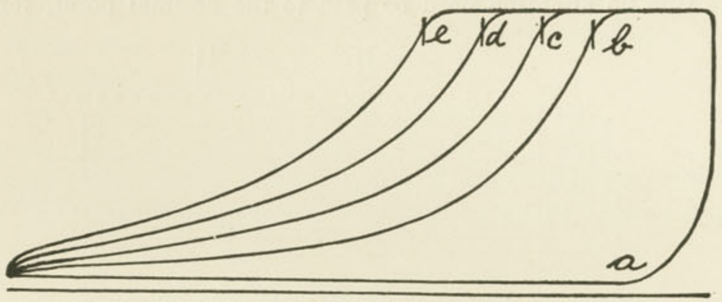


Fig. 21

driving ventilating fans. If, however, the load varies from stroke to stroke, the indicator will not repeat the same line, and the change in size and shape of successive diagrams will depend on how fast the load varies and how the governing mechanism alters the steam distribution to meet changes in load.

Consider three simple engines, all receiving steam at equal pressure and exhausting against equal back pressures. The first has a drop cut-off valve gear; the second, a piston valve operated by a shifting eccentric carried on a shaft governor; the third, a throttle governor and a slide-valve operated by a fixed eccentric. What will be the change in consecutive indicator diagrams from each when in say a few seconds the load increases gradually from half to full power?

The half load card from the first is like *b a*, Fig. 21. Increase in load slows the engine down a trifle. A heavy fly-wheel

is used to prevent serious fluctuation in speed; nevertheless, a very slight retardation occurs, and the governor, usually of the pendulum type, descends a minute fraction of an inch, draws back the knock-off cams, and so delays the cut-off. The next card is consequently like *c a*, the next like *d a*, and so on till finally the work done by steam per revolution is once more adjusted to that required to keep the shaft turning at approximately the same speed. Successive cards differ principally in the position of cut-off and in the expansion line. The exhaust line will perhaps become a trifle higher, though very little, and if the engine continues to run at full load the compression line too will be altered, due to change in cylinder temperature, but, roughly, the expansion line alone will change.

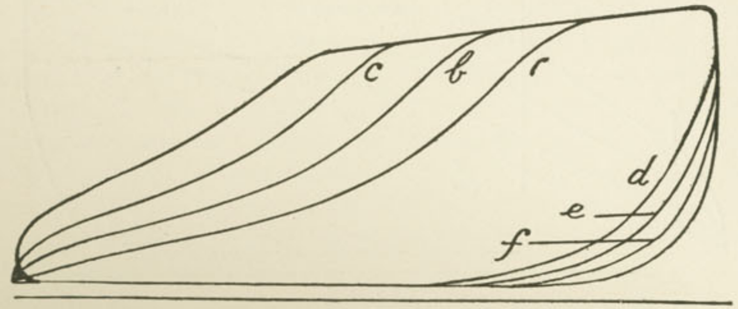


Fig. 22

In the second engine, retardation due to increase in load may be less than in the first, for shaft governors are designed to shift very quickly with the slightest change in speed. When the governor moves it decreases the angular advance of the eccentric, and may or may not increase the valve travel. Usually it delays not only the cut-off but all other events of the stroke. Successive cards will then be like *a d*, *b e* and *c f*, Fig. 22, the changes in cut-off, release, and compression being very noticeable, even though high speed and the nature of the valve-gear combine to prevent decided changes in slope at the time of these various stroke events. The change in admission is not so apparent, for when that event takes place the card is close to its dead point and almost stationary.

For the third engine stroke events always occur at the same positions, because the valve motion is invariable. While the engine runs at half-load, however, to regulate the work done in the cylinder per revolution to that necessary for maintaining constant speed, the governor throttles the steam, and by providing only a small opening for it to pass through on its way to the slide-valve, reduces its pressure by wire-drawing. The half-load card is like *a b,* Fig. 23. Slight retardation due to increased load changes the governor position, enlarging the passage through the throttle-valve, so that the next card is like *a c,* etc.

A difference in these three methods of governing is shown clearly by the indicator cards. The first meets an increased load by allowing steam at full pressure to push the piston through a longer distance before being cut off. The second does likewise,

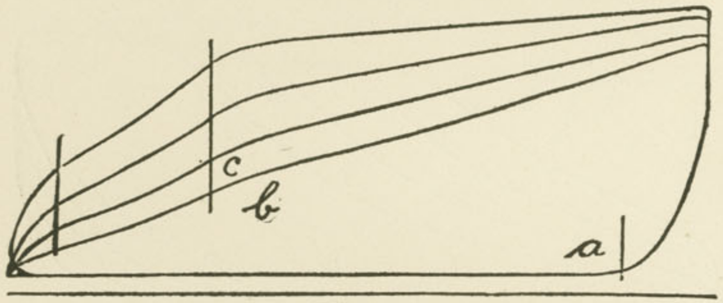


Fig. 23

but also modifies the rest of the steam distribution. The third does not change the time of stroke events, does not alter the distribution, but increases the pressure of steam supplied.

Consecutive diagrams from a small automatic shaft-governed engine, used, let us say, for driving an elevator, may show all gradations from a very narrow diagram in which the back-pressure and expansion lines almost coincide to a full area corresponding to heavy load, if the indicator pencil is pressed against the paper while the elevator is being started. Sometimes eighteen or twenty such diagrams are perfectly distinguishable, but for loads rapidly increasing and then decreasing the lines soon overlap and become unintelligible.

Certain classes of engines, such as those driving rolling-mills or street-railway generators, are subjected to violent fluctuations in load, occurring almost instantaneously when, for instance,

an ingot enters the rolls, or when a number of electric cars happen to be started simultaneously. Locomotives, too, running on a track with numerous short, steep grades, or with many switches and crossings, necessitating frequent change in speed, are required to work at widely differing rates, according to the positions in which the engineer momentarily sets the link or the throttle. Measurement of the power of such engines by means of the indicator demands great skill and the very best judgment. A single diagram, representing, as it were, a snap-shot of the power developed in one particular revolution, may represent full load or no load or any intermediate condition, but is not likely to show the average load. A number of diagrams taken at equal intervals will probably average nearer the true mean value, but if the fluctuations are great a large number of cards may be necessary to get anything like accuracy. A good way to obtain the power of such engines is to decide on a definite time interval for taking cards, making it as short as possible, and at each time to keep the pencil in contact with the paper for three or four revolutions, depending on circumstances, or until as many diagrams are drawn as can be distinguished without confusion, then to planimeter each diagram and find the average M.e.p. for each series. In this manner an attempt is made to catch the momentary changes in load as well as those occurring slowly.

Engines driving factories, shops, or textile mills are not often subjected to sudden changes in load, because their power is distributed among a large number of relatively small machines, and it is quite unlikely that many of them will be started or stopped at the same instant during working hours.

Variation in consecutive diagrams is sometimes due, not to real variation in load, but to instability, or *racing,* of the governor. With springs and weights improperly adjusted, a governor will sometimes *race,* or *hunt,* back and forth from one extremity to the other, often accompanied by serious fluctuations in speed. The diagrams of Fig. 24 show the variation in work done per revolution by an engine with riding cut-off valve and throttle governor. The variation was due simply to racing, for the load was known to be uniform. These diagrams show also a faulty setting of the main eccentric, giving no compression and too late release. The speed was low, otherwise the lateness of admission would have been apparent. Late release does no harm for the degree of expansion shown, but absence of compression probably causes the engine to use from 5 to 10 per cent more steam than necessary.

The ideal instrument for measuring indicated power under rapidly varying load is some form of continuous indicator. Several devices of this sort have been patented; some are on the market, but all are too complicated for practical use under ordinary conditions. Most of them produce diagrams like the ordinary indicator, but take them on a roll of paper, which is advanced each revolution, so that consecutive diagrams are separated far enough to be distinguishable. An attachment of this sort applicable to

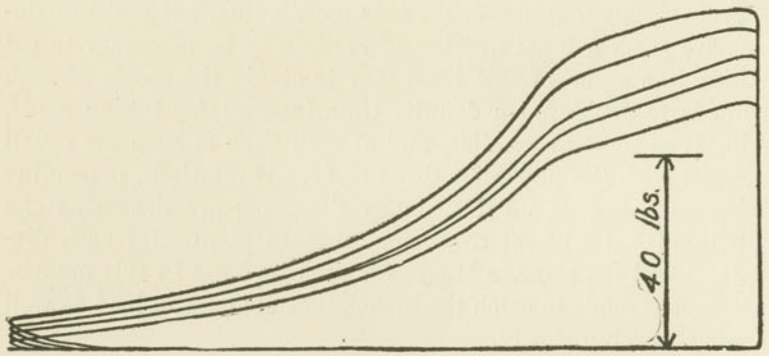


Fig. 24

the Crosby indicator in place of the ordinary drum is made in Germany, and is said to be used for locomotive testing.

In measuring indicated horse power what is desired is not an instantaneous observation of what the engine happens to be doing at one particular instant, but an average value of what it does during a protracted interval. In taking cards from a compound or triple-expansion engine, therefore, there is no necessity for taking all the diagrams exactly simultaneously. Just as reliable data can be obtained by taking cards from the different indicators always in the same order and at equal intervals. Thus a single observer can easily take all the cards from a three-cylinder engine once every ten minutes by taking a card from each indicator say one minute later than from the preceding one. Except where changes in load are very sudden this method is satisfactory.

However, some engineers prefer to take all the diagrams exactly at the same instant, so that one card may be compared with another for studying changes in pressure as well as power developed. For this purpose electro-magnetic attachments are sold which can be clamped to any indicator and serve to bring the pencil into contact with the paper. The engineer goes to each instrument, putting on fresh cards and opening the indicator cocks. Then he presses the pencil motion of one indicator against its drum. This closes a circuit operating all the others. Such attachments are particularly valuable for indicating engines with several cylinders at considerable distances apart, and strokes so

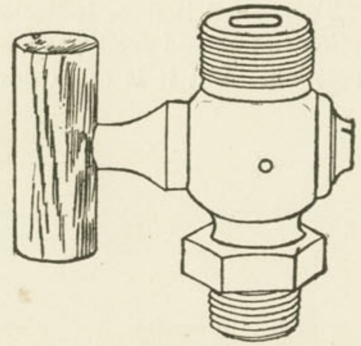


Fig. 25

long that it may be advisable to use two indicators on each cylinder.

The indicator is often used to measure power supplied to a single machine, such as a geared pump, a belt-driven air-compressor, a loom or a printing-press. Cards are taken from the engine when the machine is running, and again when not running, care being taken to keep the loads on other machinery exactly the same during both measurements. The difference in the indicated horse-power is usually taken for the power delivered to the machine in question, assuming that friction of engine and shafting is the same at both times. This is never quite true, and may involve an appreciable error unless the engine under the lightened load is held down to its former speed. The accuracy obtainable is greatest when the machine requires a large fraction of all the engine output.

Attaching the Indicator. The indicator is attached to an engine by either a straight or a three-way cock, shown in Figs. 25 and 26. These are special valves with accurately ground taper plugs. A small hole through one side of the plug and another through one side of the body, Fig. 27 (a), serve to let air penetrate from the engine room to the lower side of the indicator piston when an atmospheric line is to be drawn. Fig. 27 (a) shows the proper position when shut. If the plug were turned 180°, like 27 (b), steam under pressure would blow up through *a* and out at *b*; or air would be sucked in at *b*, and down through *a* into the engine cylinder if there were a vacuum within. In the latter case the leak might go undetected and the vacuum be thereby impaired. To prevent it some indicator cocks have stops which limit the motion to 90° and facilitate the action of opening to just the right position. But it is often desirable to turn the

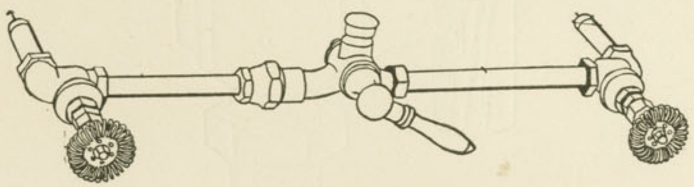


Fig. 26

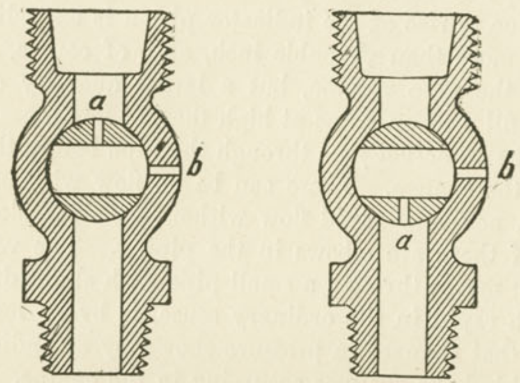
cock, as in Fig. 27 (b), to blow out water from the pipe and not let it enter the indicator, and for this reason many engineers file off the plug stops. The handle of a three-way cock should stand *exactly* in mid-position when an atmospheric line is drawn.

All indicator cocks of American manufacture have standard half-inch pipe threads for connection with the engine, but they have special machine threads and internal tapers to fit the different makes of indicators. This is worth remembering, for it necessitates the use of an adapting union (sometimes not easily obtainable) whenever an indicator of one make is to be used on an engine fitted with cocks of another.

If possible, the indicator should be placed in a vertical position, so that weight and friction of moving parts will always exert the same effect upon the spring. It is tested in this position. With a weak spring, say less than 20 pounds, a slight difference in the atmospheric line and an appreciable error due to friction

may possibly be detected if the indicator is first placed upright and then laid over horizontally; but with a stiff spring, 40 pounds or more, if a vertical position is impracticable, or very inconvenient for any reason, no hesitation should be felt in setting the indicator horizontally, and no error need be anticipated.

Large engines are usually provided with tapped holes for indicator connections when built; engines with cylinders less than 12 inches diameter seldom are. For temporary work in testing small engines the cylinder drips may be utilized. A tee may be inserted in each drip pipe with a valve just below, and the indicator piped from the branch of the tee. Thus the drips may still be kept in service and shut off only when cards are taken. But



27(*a*) 27(*b*)

such an arrangement is advisable only as a makeshift, because drip pipes are seldom over $\frac{3}{8}$ inch and not large enough to properly conduct a fluctuating steam pressure to the indicator except at low speed.

The best place to tap an engine for indicators depends on the design of the cylinder and the direction in which the cord must lead to the crosshead reducing motion. Sometimes the pipes enter the cylinder heads, but this position is usually inconvenient. Horizontal cylinders may have holes either on top or at the side. At the top an indicator cock may be screwed directly into the cylinder, with the double advantage of a straight, short passage for steam and no chance for water to collect. If at the side, a close nipple and a long-sweep elbow should be used, so that the indicator may stand vertically, or a special form of elbow cock may be obtained. The side position generally affords a better chance for leading the cord to the crosshead, and for large cylinders it is preferable because of accessibility. In either position a three-way cock and a single indicator may be used instead of two straight cocks and two indicators. Piping for three-way cocks is usually ½ inch, except for large cylinders, where, on account of the excessive length required, it is made ¾ inch to prevent loss of pressure due to friction and condensation.

The influence of long piping on the indicator diagram deserves attention. Every time an engine admits steam, changing its pressure from, say, 4 to 100 pounds, enough steam must enter the indicator pipe to raise the pressure therein. The enlargement of volume due to rise of the indicator piston is exceedingly small, usually not more than $\frac{1}{16}$ cubic inch, and, of course, there is no increase in the pipe volume, but a larger quantity of steam is required to fill a given space at high than at low pressure, so that there must be an *actual flow* through the pipe before the indicator can record the change. There can be no flow without difference in pressure, nor very rapid flow without considerable difference, especially if there are elbows in the piping. The velocity with which steam moves through a small pipe with slight drop in pressure, though rapid in the ordinary sense, is by no means instantaneous, so that changes in pressure shown by an indicator surely must lag behind the changes occurring in the engine. This tends to raise the steam and expansion lines and lower the compression line. But, except at high speed, if the pipe is smooth inside and not over 3 feet long the error so caused is probably less than certain others to be mentioned later. Long pipes ineffectually drained of the steam condensing and collecting in them may cause very great difficulty in using the indicator. Accumulated water is blown to and fro by change in pressure, and a violent water-hammer results, striking the indicator piston so suddenly that the pencil vibrates up and down sometimes an inch or more, and renders the diagram worthless as a record of pressure changes. A case may be cited where water-hammer in an indicator broke the cylinder and destroyed the pencil mechanism; another where on a vertical engine, after the cock had been shut to protect the instrument from injury, a sudden, more violent hammering split the pipe

for a length of six inches. In the first case the engine was started quickly after a long standstill without first blowing out the drips, so there probably was considerable water in the cylinder. In the second, the boilers supplying steam were priming very badly, and water was pocketed in the vertical pipe leading down from the top of the cylinder to the indicator. In both there really was severe water-hammering in the engine, evidenced by lifting of the relief valves, but there was no such shock as would have been apparently recorded by the indicator in either case, for such a pressure would certainly have wrecked the engine. Vertical engines likely to receive sudden doses of water should have valves on the indicator pipes as close to the cylinder as possible to protect against water-hammer.

The length usually chosen for indicator diagrams is between 3½ and 4½ inches. From 2 to 3 inches would be just as good in every case and very much better for cards at high speed. The height seldom exceeds 2 inches, and there is no good reason for having the length much greater; the average height or mean effective pressure cannot be obtained with greater precision by merely lengthening the diagram, and changes in shape at cut-off, release, and compression are rendered less distinct by elongation. Elasticity of the indicator cord, and excessive torsion in the drum spring combine with inertia to produce a slightly longer diagram at high speed than at low. The percentage elongation is less for short diagrams. If the elongation were uniform throughout the stroke it would introduce no error in the measurment of horse-power, for the area of a card would be increased in the same ratio as its length, and the mean effective pressure would therefore remain unaltered; but unfortunately it is greatest at the ends, and moreover it is not the same at both ends. Ordinarily, no allowance is made for this error in computing mean effective pressure—an additional reason for not giving more than three significant figures in reporting indicated horse-power.

Reducing Mechanisms. Various devices are used for reducing the stroke. The one shown in Fig. 28 in connection with an indicator is the Crosby reducing wheel. It is clamped to the indicator cock by a union *4*, and the indicator is clamped to it back of the spring barrel *14*. The cord *24* is hooked to the crosshead. The indicator cord is wound on any one of a nest of aluminum drums *20*, whose diameters are chosen to accommodate all lengths of piston travel from 18 to 72 inches. Reduction is effected by bevel gears and by the difference in size of the aluminum drum and the indicator drum. A helical spring in *14* can be tightened by the nut *16* and serves to re-coil the cord *24* on return of the crosshead. In this it is assisted by the spring in the

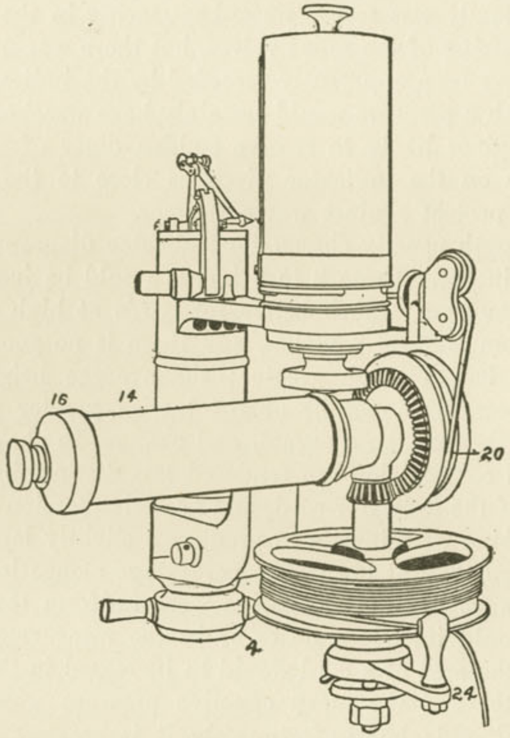


Fig. 28

indicator drum. Reducing wheels are criticised by some engineers on the ground that backlash of the gears, inertia of the wheels, and variation in diameter of the cord coiling about a very small diameter must certainly introduce errors in the diagram. But the backlash is really negligible, for the gears are accurately cut and the spring presses them always in the same direction. Inertia is minimized by using aluminum wheels. Tests on an engine having 18-inch stroke showed that the diagram was elongated only about 1.5 per cent over its proper length even at the relatively

high speed of 250 r.p.m. At speeds up to 150 it was substantially correct. Variation in length due to lack of uniformity or elasticity of the cords may be guarded against by using specially prepared braided line of firm and even texture. The reducing wheel is reliable, and so easily applied for testing horizontal, stationary engines that it may be considered almost a necessary part of an indicator outfit. It is, however, not generally appli-

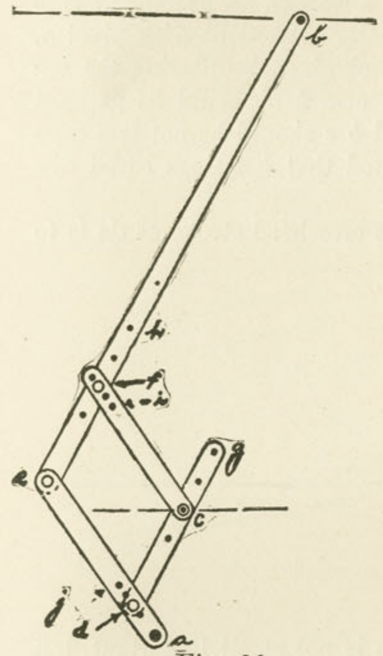


Fig. 29

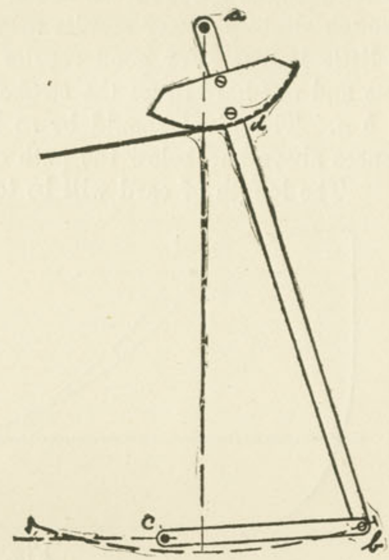


Fig. 30

cable to vertical engines, for often the crossheads cannot be reached from near the indicator.

The pantograph, Fig. 29, is an accurate reducing mechanism. Point *a* turns on a fixed pivot fastened to the floor, the engine frame, or any rigid support. The hole *b* is slipped over a pin carried on the crosshead, and travels back and forth in a straight line. The indicator cord is hooked to the stud *c*, which travels in a straight path parallel to that of *b*. The pantograph can be adapted to engines of different strokes by shifting the links *c f* and *c d*, always keeping *c* in line with *a* and *b*. The proportions for constructing and setting up are:

$$\frac{a\,d}{a\,e} = \frac{\text{Desired length of diagram}}{\text{Crosshead travel}} = \frac{e\,f}{e\,b}$$

$$ed = fc;\ ej = ic;\ dc = ef;\ dg = eh, \text{ etc.}$$

The Brumbo pulley, Figs. 3 and 30, is easily made and quite satisfactory as a reducing rig. It has a wooden arc fastened to the swinging arm *b a* with its center usually coincident with pivot *a*, though slightly better results may be obtained by placing the arc a little lower. For good results the arm *b a* should be at least one and one-half times the stroke and *b c* should be not less than $\frac{1}{3}$ *b a*. The pivot should be so located that *b* swings equal distances above and below the path of *c*.

The length of card will be to the crosshead stroke as *da* is to

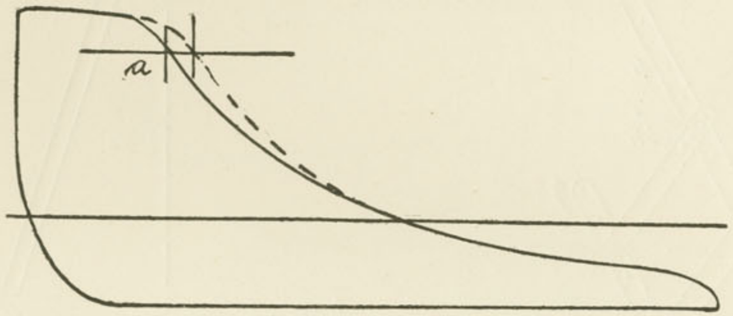


Fig. 31

ba. The exact ratio of this reduction is not at all important, but a constant ratio should be maintained throughout the stroke. In other words, when the piston has reached $\frac{1}{4}$ stroke the indicator drum should have turned through just $\frac{1}{4}$ the distance it turns in a full stroke. Suppose the continuous line of Fig. 31 shows a card drawn by an indicator with faulty reducing rig, and investigation proves that when the pencil was at *a* at 21 per cent stroke the crosshead was at 25 per cent stroke, etc. The card is then not a true record of pressure-volume changes in the engine, but should be modified by moving point *a*, etc., toward the right, as shown by the dotted line. This will change the area and consequently the indicated horse-power. Sloping lines near the ends of

the diagram would be most affected and horizontal lines not at all. Cards from engines having late cut-off by slide valves would suffer comparatively little change in area on account of the gradual slope—a fortunate circumstance, because marine engines, which are of this class, often are fitted with very inaccurate reducing rigs. A Brumbo pulley arranged like Fig. 30 cannot be made exact for all parts of its stroke, and should not be used for close work unless its errors are approximately known, so that an estimate can be formed of their effect on the indicated horse-power. It can be tested by setting the engine at several definite points of the stroke and marking the corresponding positions of the indicator drum, or it can be drawn to scale in several positions and the

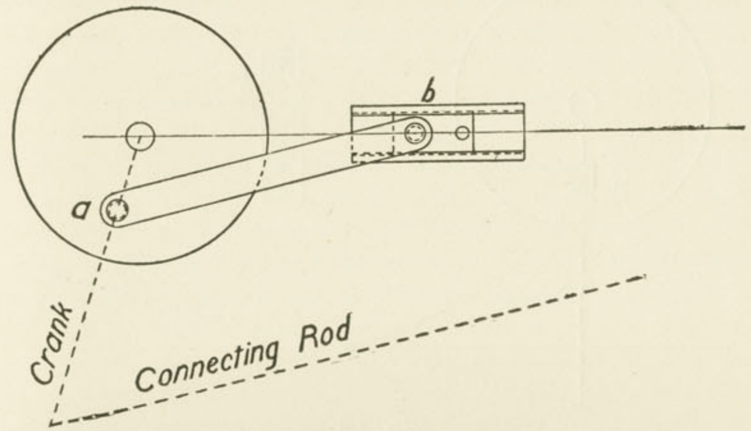


Fig. 32

errors determined by spacing along the cord arc. Except at light loads, if the position error is in no place greater than 1 per cent, the rig is probably good enough.

For engines of the enclosed type, which have the crosshead and connecting-rod completely surrounded in a sheet or cast iron casing to prevent spattering oil, the reducing mechanisms described above are not applicable. In such cases the indicator may be operated by an eccentric placed on the engine shaft and set parallel to the crank, so that the indicator drum and the piston will move in unison. The eccentric should have about $1\frac{1}{2}$-inch throw, so that it will give a 3-inch card. For correct reduction the following proportions must be adhered to:

$$\frac{\text{Length of eccentric-rod}}{\text{Throw of eccentric}} = \frac{\text{Length of connecting-rod}}{\text{Length of crank}}$$

If the shaft is of large diameter, or if only the ends are accessible, so that an eccentric would be impracticable, a pin may be set in one end of the shaft in line with the crank, and the rig made as suggested in Fig. 32, the straight line guide being supported rigidly in any convenient manner. A cord hooked to the pin shown on this miniature crosshead may be led to the indicator. An approximately correct rig, dispensing with the rod *a b* and the straight line guide, is shown in Fig. 33. The indicator

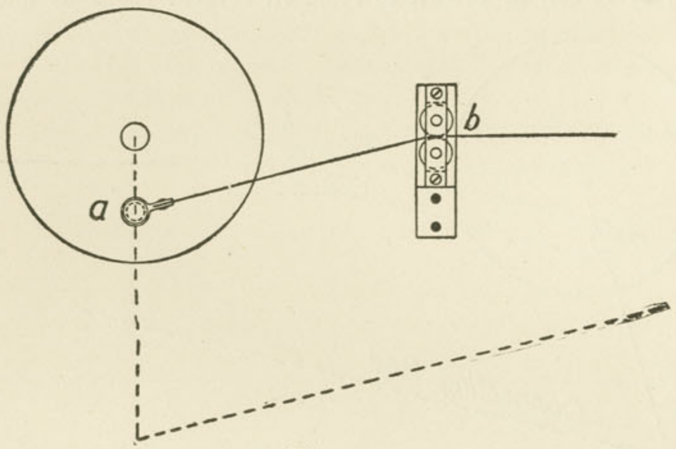


Fig. 33

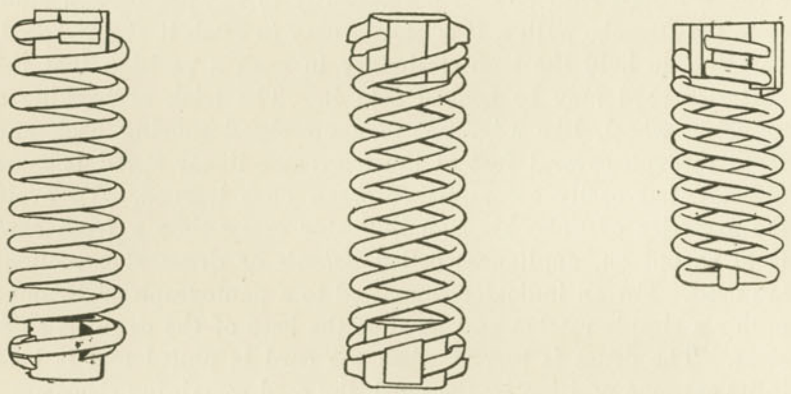
cord is tied to a wire ring fitting loosely in a groove around the pin *a*, and leads between two stationary guide pulleys at *b*. From there it runs to the indicator around as many other guides as necessary. Sometimes a steel tape or very flexible wire is used in place of the cord, in which case precautions must be taken to prevent it from ever becoming slack. As the shaft turns, the connecting-rod of this rig varies in length, so that the reduction of motion is not the same for all parts of the stroke. Its error of motion is not the same for all parts of the stroke. Its error is, however, easily studied on the drawing board, and can usually be made small by properly locating the guide pulleys at *b*. Rigs of this description are often used for Westinghouse engines. Their worst fault lies in the extremely long cord or tape required

and the difficulty of properly guiding it between the shaft and the indicator. The stretching and whipping of a long cord at high speed may introduce serious errors in the diagram.

The cord running from a pantograph or a reducing wheel to an indicator must at first lead exactly parallel to the piston-rod. It may afterwards turn over a guide pulley and lead to the indicator in any direction. The cord from a Brumbo pulley must leave in the plane of the pulley, but may lead in any direction, up or down. Hooking the indicator cord to the pantograph or other reducing mechanism of a high-speed engine requires a knack which some persons acquire only after considerable practice. If a short, looped cord be tied permanently to the pantograph stud, or to the Brumbo pulley, it is always easy to catch it at any speed, and then to hold the loop stationary in such a position that the indicator cord may be hooked into it. The trick of hooking a reducing wheel, like Fig. 28, to a crosshead moving back and forth through several feet at much greater linear speed is more difficult, but easily accomplished when once learned. To avoid the necessity of unhooking an indicator every time a fresh card is to be put on, appliances called *detents* or *drum stop motions* are used. For an indicator connected to a pantograph or Brumbo pulley a simple ratchet and pawl at the base of the drum is sufficient. The drum is turned when the cord is pulled and is held in its extreme position by the pawl, the cord remaining slack until the pawl is snapped out. With a reducing wheel a more elaborate disengaging device is necessary. It is placed between the wheel and the drum and is designed to stop the drum without letting either cord become slack. A slack cord on a reducing wheel is very likely to entangle the whole mechanism.

Care should be used in knotting and adjusting the length of an indicator cord, so that the drum will turn midway between its stops. This places the diagram in the middle of the card, and also insures that a slight stretching or displacement of the cord will not cause the drum to strike either stop and shorten the diagram.

Springs. Three of the principal forms of indicator springs are shown in Fig. 34. The change in length of a helix subjected to a given force depends on its length, the size and elasticity of its wire, the diameter of its coils, and the number of coils per inch. These factors are chosen to suit the scale a spring must have and the pencil motion with which it is to be used, and then a final adjustment of the spring is made either by grinding the wire and so changing its diameter or by screwing the coils into the end pieces more or less, thereby changing the length. Springs like (a) and (b) are alike at both ends and necessarily heavier than (c); besides their centers of gravity are farther down than that of (c), so that the effect of vibration due to sudden changes in pressure is more pronounced. On the other hand, (c) changes its helical shape in a straight branch connecting the two coils at the bottom. At the middle of this wire the axial force is applied, and the total elongation or contraction which would be



(*a*) (*b*) (*c*)

Fig. 34

produced in the helices alone is slightly modified by flexure of the straight branch.

The effect of temperature in altering the scale of a spring is important, and constitutes one of the greatest sources of error. Indicators of the *inside-spring* type, shown in Fig. 2, have the spring out of contact with steam, except that which leaks by the piston, but this leakage, together with the conduction through the metal, keeps it very hot. Its temperature probably fluctuates a little, never becoming as high as that of steam at the throttle, and not often as low as the exhaust. The same temperatures ought to be reproduced in testing a spring, but this is practically impossible, so the test is usually made by subjecting the spring (in its indicator) to a quiescent, gradually increasing steam pressure, and comparing the pressures shown with the readings of a gage

or a mercury column. Saturated steam at a given pressure always has the same temperature, so the conditions imitate, in roughly approximate fashion, those which exist in use on the engine. A *test card* is given in Fig. 35. It shows at the left the pencil heights corresponding to the true pressures (in figures) while the pressure was increasing, and at the right the heights corresponding to exactly the same pressures when decreasing. A perceptible departure from the correct scale at higher pressure and a decided lag on the downward scale, due to weakening of the spring by

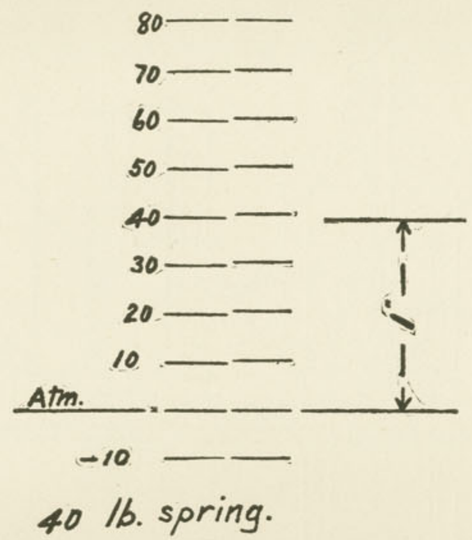


Fig. 35

heating, will be noticed. The mean of the two scales may be taken as the indicated pressure, and diagrams may be corrected for the departure from true pressure in case the spring is much in error; however, this involves so much labor that it is seldom done. It is better to use a new spring known to be approximately correct.

Errors due to temperature may become serious in indicators used for superheated steam or for gas or oil engines. Here the temperature bears no definite relation to the pressure and may become so high as to alter the scale considerably. The maximum temperature of springs in gas engine indicators is not known, but it is so high that cylinder oil is often burned hard onto the nickel plating. At such a heat the scale is probably quite different from that when cold, yet no facilities are available for testing under actual conditions of use.

To remove the spring from the influence of heat, indicators with outside springs have recently been invented. Fig. 36 shows one made by the Crosby Steam Gage Co. The spring is on top, where it is always cool and easily accessible for changing

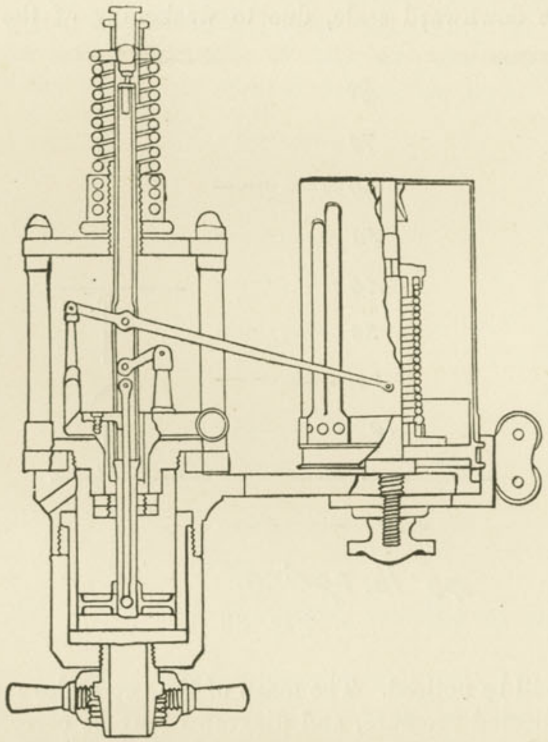


Fig. 36

in case a different scale is wanted. The somewhat heavier moving parts than those of Fig. 2 make a larger piston advisable. Its area is 1 spuare inch, and it is ground spherically to prevent cramping. Test cards corresponding to Fig. 35, taken with this indicator, show exactly the same scale ascending and descending.

For indicating gas engines smaller pistons are used, the old style instrument being otherwise like the standard steam engine

indicator shown in Figs. 1 and 2. The newer gas engine indicators have outside springs like Fig. 36, and are much superior.

For recording extremely high pressures developed in some air compressors and pumps and for studying the pressures generated by explosions, indicators are made with pistons having an area of only .025 spuare inch, as the diameters can easily be ground to within .0001 inch, the records of such indicators are nevertheless reliable.

A typical card from a gas engine working on the *four-stroke* or *Otto* cycle is shown in Fig. 37. The filling stroke, during which gas and air are drawn into the engine, is shown by *a b c* and indicates a pressure dropping below the atmosphere; if the

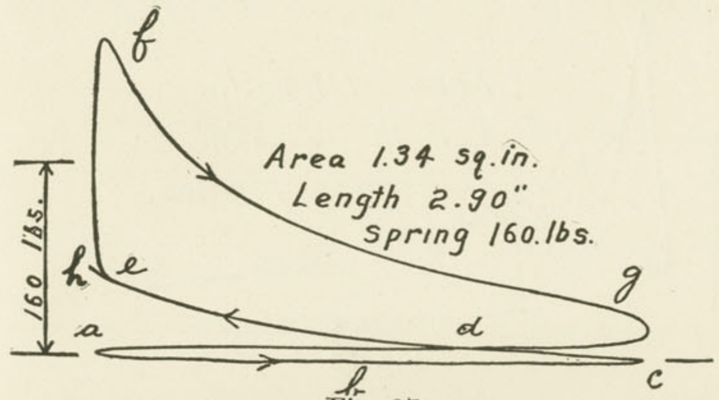


Fig. 37

pressure were not less than atmospheric no air could enter the cylinder. *c e* is the compression stroke, during which the pressure rises to about 60 pounds. At *e*, apparently just before the dead point, explosion occurs, caused by an electric spark in the cylinder. The spark really occurs a little before point *e*, but explosion is not quite instantaneous, and moreover the indicator is a little slow in responding to the change. The explosion line *e f* is not vertical if the engine is operating properly, but slopes to the right a very little, and the maximum pressure *f* is reached after the crank has passed its dead point. The expansion line should be a smooth curve like *f g*, but with certain mixtures of gas and air the explosion is so violent that the indicator is thrown into rapid vibration, producing a card like Fig. 38. Often this cannot be prevented. At *g*, Fig. 37, the exhaust valve opens and burnt gases are pushed out during the stroke *g d a*. The area of the upper loop *e f g d* represents work done *by* the gas *on* the piston, the lower, *d a b c*, *by* the piston *on* the gas. In finding the mean effective pressure one should be subtracted from the other to get the net area. This can be done easiest by starting the planimeter, say at *f*, and tracing thus: *f g d a b c d e f*. The positive area is therefore traced clockwise and the negative counter-clockwise, the planimeter giving the difference from which the M.e.p. may be found. Without a planimeter the method explained for Figs. 15 and 16 may be used.

Gas engines operating on the "hit-or-miss" principle

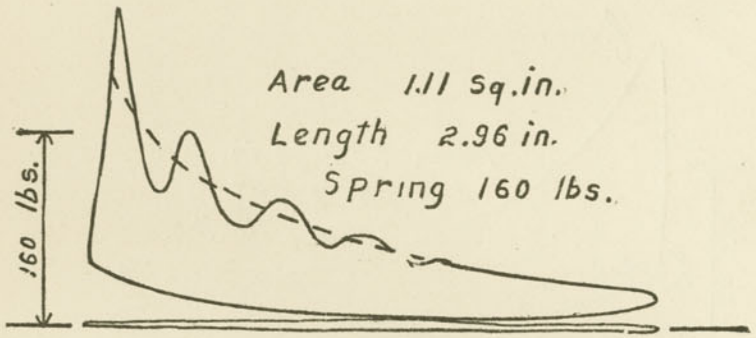


Fig. 38

(which class includes most stationary engines less than 100 H. P.) develop their maximum power when firing every second revolution. Under such conditions the indicated horse-power is

$$\text{I.H.P.} = \frac{\text{M.e.p.} \times \text{Piston area} \times \text{Stroke in ft.} \times \frac{\text{R.p.m.}}{2}}{33{,}000}$$

These engines are all single-acting.

At light load the action is different, the number of explosions necessary to maintain uniform speed being less than half the number of revolutions. The sequence of events in succeeding revolutions at full load is: fire, miss, fire, miss, etc. At light load it may be: fire, miss, miss, miss, fire, miss, miss, miss, etc., or any other combination. When the governor prevents gas from entering the engine a full charge of air is admitted along *a b c* and compressed along *c d e h*. The spark occurring at *e* produces no explosion, because no gas is present; therefore, compression continues to *h*, and then the air re-expands, tracing a line slightly lower than *h d c*, but almost coinciding with it. Then the exhaust valve opens and the air is expelled, tracing a line (not shown) which starts at *c*, rises a little above atmospheric pressure, and finally ends at *a*. The area included between this line and *a b c* represents work done by the piston each time an explosion is missed, *to pump air into and out of the engine.* It must be allowed for in calculating the indicated power if accuracy is desired. The height of the negative loop *a b c d a* is usually small compared with the rest of the diagram, and often its lines coincide so

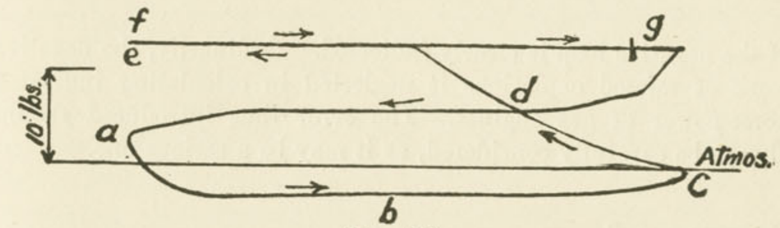


Fig. 39

nearly with the atmospheric line that an indicator in perfect order with a sharp tracing point is required to separate them. It is best in such a case not to draw the atmospheric line in the usual manner, but to shut the indicator cock and then draw a short line at the left of *a* and another at the right of *c*, and later to connect the two with a pen or a sharp lead pencil.

To magnify the lower part of gas engine diagrams for the purpose of studying the action of valves and ports more closely, a weak spring may be used with a stop placed above the indicator piston to limit its upward motion, so that the high pressure of compression and explosion may not destroy the spring. The stop usually consists of a short tube slipped loosely over the piston-rod below the cylinder cap. The card then drawn is like Fig. 39, in which the letters correspond to Fig. 37. Compression raises the pressure until the stop strikes the cap, after which the piston can rise no higher and the pencil traces a horizontal line. At *e* the explosion takes place, but the pencil finishes the stroke and begins the expansion *f g* at a constant height. Only after the pressure has decreased again to less than that corresponding to the stop line can the pencil descend. In this diagram the character

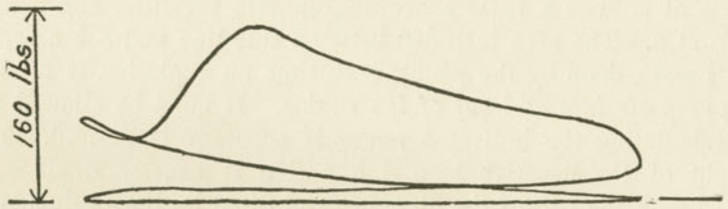


Fig. 40

of the negative loop is clearly indicated. Ordinarily, the negative work of missed explosions is neglected in calculating indicated horse-power of gas engines. The error thus introduced should always be carefully considered, as it may be a serious one.

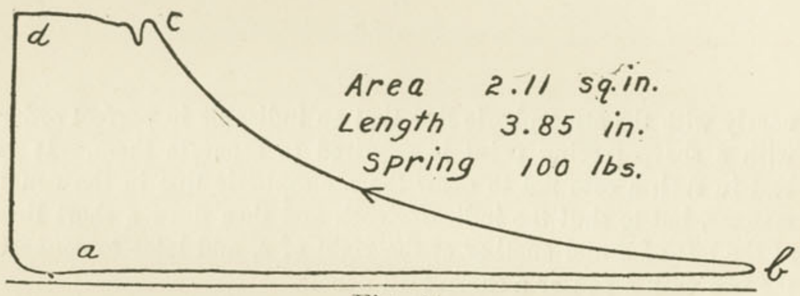


Fig. 41

A stop motion can often be used to advantage in studying the lower parts of steam engine diagrams.

A card from a gas engine with ignition too late for good economy is shown in Fig. 40.

Fig. 41 shows a card from an ammonia compressor. Like all compressor cards and pump cards, it represents work done *by* the piston *on* the fluid. Ammonia vapor is drawn in along *a b*, compressed along *b c*, and forced out of the cylinder along *c d*. The line *d a* represents expansion of what little ammonia is left in the clearance space as the piston starts on its next filling stroke. The clearance on all compressors is very small.

Fig. 42 is from an air compressor with piston 14 inches

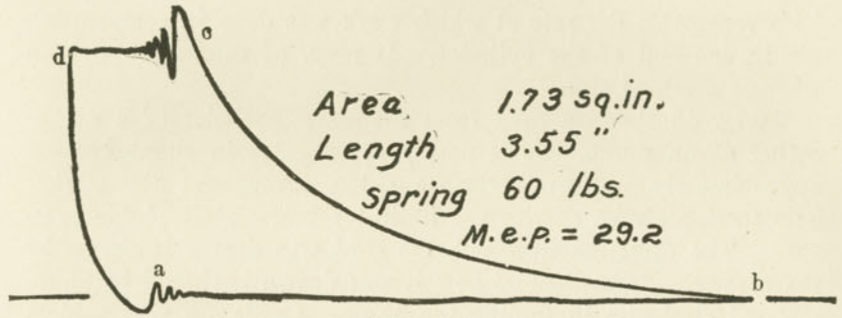


Fig. 42

diameter and 16 inches stroke. The speed was 100 r.p.m., and the discharge pressure 78 pounds per square inch. Air was drawn from the room along *a b*, compressed along *b c*, and forced into a receiver at approximately constant pressure along *c d*. The inlet and outlet valves of most compressors are actuated by differ-

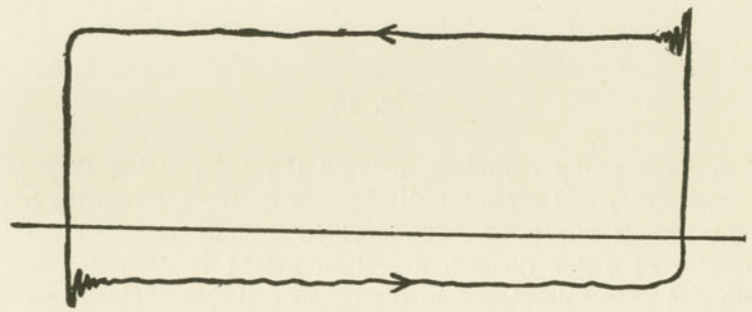


Fig. 43

ence in pressure. Notice that the inlet valve did not open till *after* the pressure in the cylinder had dropped *below* atmosphere, to *a*. This slight difference was necessary to lift the valve. The same occured before delivery, the pressure rising several pounds higher than in the receiver before the outlet valve opened. The sudden equalization following set the indicator pencil vibrating. The indicated horse-power corresponding to this card was:

$$\text{I.H.P}\frac{29.2\times14^2\times.785\times\frac{15}{12}\times100}{33,000}=18.2.$$

This represents the rate at which work was done in compressing air in one end of the cylinder. It may, of course, be written without a minus sign.

Fig. 43 shows a card from the water cylinder of a direct-acting steam pump. It is nearly rectangular in shape because approximately uniform pressure exists throughout the stroke. The suction stroke carries the indicator below atmospheric pressure. The direction in which the card was drawn is shown by the arrows. Regardless of how it was drawn it should be planimetered clockwise in finding the M.e.p. Cards are very seldom

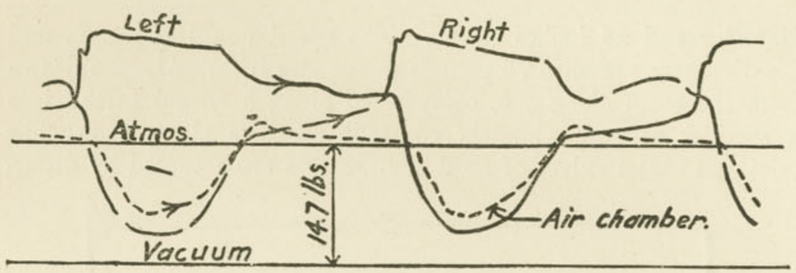


Fig. 44

taken from pump cylinders, because the information they give is unnecessary and often unreliable. In testing a pump the horse power output or rate of doing work in actually raising a certain quantity of water through a certain height is desired, not the indicated power developed in the pump cylinder. The former is less than the latter, because of resistance to flow of water through valves and passages. The card of Fig. 43 was taken at low speed. At higher speed the very rapid changes in pressure produce severe water-hammer, which soon ruins an indicator for accurate work.

The indicator may be used to study the action of various other machines. Fig. 44, for instance, shows a combination of three diagrams taken simultaneously from a pulsometer. Three

indicators were used and separate diagrams taken from the left side, right side, and air chamber, cords being pulled uniformly by a special mechanism. The diagrams were then superposed, as lettered, and serve to give valuable information concerning the action of this peculiar form of steam pump.

Taking Cards. Before using an indicator with which one is not familiar it is well to study the sectional cuts given in the manufacturer's catalog and to follow explicitly the directions given for adjusting and handling. Take the instrument all apart and note particularly: how the spring is attached to the piston; how the piston is fastened to its rod; what must be done to raise or lower the atmospheric line. Note also where left-hand threads are used. The three best known makes of indicators differ in detail, so that instructions for one would not apply to the others, but a few general directions may be of service.

Remember, in the first place, that the instrument is delicate —" built like a watch "—and should be handled accordingly. Its light pencil pantograph is made of spring steel and will seldom break, but may easily become bent and thus spoil the accuracy with which pressure is recorded. Test it frequently to see that it draws a stright vertical line when the drum is stationary. A micrometer depth gage inserted in the bottom of the cylinder against the piston may be used to test the accuracy of multiplication. For this test the spring should be removed. Joints in the pantograph should have no perceptible backlash and yet be loose enough so that when disconnected from the piston the linkage will drop freely by its own weight. The piston should slide loosely enough in the cylinder so that when wiped clean and dry and connected to the pencil motion without the spring it will drop by gravity without sticking in any place. When the bottom of the cylinder is closed air-tight by pressing one finger against it, the piston should descend very slowly yet steadily from top to bottom, air leaking out between it and the cylinder. If the piston is not free enough to fulfil this requirment it is probably tight enough to stick when used. Indicator pistons have shallow grooves or *water packing rings* to prevent leakage of steam. When new they leak very little, even at high pressure. Until badly worn the leakage is not objectionable, for it is relieved through vents A, Fig. 2, and so does not affect the piston height. A leaky piston is preferable to one that sticks. Lubricate the piston and all other parts freely with a light grade cylinder oil. Ordinary black cylinder oil is too thick. A brand called Rarus Cylinder Oil, made by the Vacuum Oil Co. of Boston, has been found to answer all requirements. It is not thick enough to impede the light moving parts, and it protects steel, composition, and nickel surfaces from corrosion. In use it is well to keep the hollow of the cap 2, Fig. 2, filled with this oil. Keep a can of oil in the indicator box.

Indicator cylinders are made of composition; pistons, of steel or composition, the former being preferable whenever it can be given sufficient care to prevent rusting. Indicators and indicator cocks for use with ammonia are made wholly of steel and should be very carefully dried and oiled whenever they are put away after use.

Do not wipe an indicator with cotton waste. Use a soft cloth free from dust, cinders, graphite, or fillings, and have plenty of it ready for handling the instrument when hot and for wiping your hands clean before touching the cards.

When setting up the instrument for use, ascertain what the highest and lowest pressures are likely to be, and choose a spring which will limit the extreme range of up and down pencil motion to not over 2 inches in any case and not over 1½ inches if the speed is to be more than 250 r.p.m. If the probable pressures are unknown it is wise to first use a very stiff spring and thus obtain definite information. Don't run the risk of compressing a spring so much that the pencil will rise above the drum and then catch on it and break or bend the pantograph. Set the height of the atmospheric line so that the diagram will be drawn in the middle of the card. Adjust the handle 22, Fig. 2, so that when pressed against the stop (shown in Fig. 1) the pencil will touch the card just hard enough to make a very faint line, the fainter the better, so that friction will not unduly hinder the pencil rising and falling. Keep the brass pencil sharpened to a fine point, rounded just enough to prevent scratching the paper. Don't try to sharpen it by hand as you would a lead pencil, but clamp it in the chuck of a speed lathe, so that the point may keep central and sharpen it with a dead-smooth file. Better still, keep a supply of new points on hand.

When possible, use brass pipe and fittings for indicators. If graphite must be used on the joints apply it sparingly, so that

it cannot get into the pipe. Do not attach an indicator to its cock until all the piping has been thoroughly blown out to clear it of scale and grit. With the indicator cock open, hold your hand over the steam blowing out to tell by the feeling whether any gritty particles are coming through. With a new engine or new steam pipes it may be impossible to blow out all the scale. In such a case trouble from sticking of the indicator will surely follow unless the instrument is cleaned very frequently. Some engineers use graphite in the cylinder lubricator. This usually causes difficulty in indicating. The difference in diameter between an indicator piston and its cylinder in good condition is so little that nothing but good oil and condensed steam should be allowed to get between the two.

In putting on a card be sure to wrap it *tightly* around the drum. When taking many cards for a test, mark each sheet plainly to show when and from what part of the engine it was taken. Record the make of indicator and scale of spring used and also the kind of reducing gear. Make a dimensioned sketch of the rig, unless it is known to be a correct one. If springs are changed during the test, *mark the spring on every card.* Whenever the diagram drawn is of peculiar or unfamiliar shape, notice in what direction the indicator draws it, and record the same by arrow heads on the diagram; mark also which end of the sheet—not which diagram—corresponds to the head-end dead-point. Many of the so-called "freak" diagrams published in technical papers with the request for explanation are lacking in this important information.

When ready to take a diagram first hook up the indicator cord. Look back along it to the reducing rig to see that it leads freely. In case it whips from side to side, steady it and keep it steady while taking the diagram. Next blow out water, if necessary, through the side hole in the indicator cock. Then open the cock and let the piston rise and fall a few times to warm up the cylinder. Then take the diagram, keeping the pencil in contact for one or for several revolutions, according to the information desired as explained on page 901. Do not keep the cock open longer than necessary.

Bear in mind constantly, until this caution is no longer necessary, that of all the instruments in a steam engineer's outfit the indicator is probably the most difficult with which to get really good results. Besides its inherent defects due to inaccurate springs and to inertia, it is frail and not fitted to stand rough usage, yet it must often be used where little protection can be given and where vibration and water-hammer tend to injure it as well as to render it inaccurate. Indicated power must often be directly compared with electrical power computed from the readings of ammeters and voltmeters, which instruments are susceptible of precise division and accurate calibration. If, therefore, the indicator is to be of any value for such comparison it must be handled with care and skill.

QUALITY OF STEAM AND ECONOMY CALCULATED FROM THE INDICATOR DIAGRAM.

In order to apply the indicator for scientific investigation of the steam engine, at least an elementary knowledge of the properties of steam is necessary. A course in practical thermodynamics, or the relations existing between heat and the work derived from it by the steam engine, is recommended to anyone whose time permits, but in the lack of such preparation the following brief summary may be of service.

When water is confined under constant pressure and heat is applied the temperature gradually rises till a certain definite value is reached, depending on the pressure. After that, further heating does not increase the temperature, but changes the substance from its liquid form, water, to its vaporous form, steam. During evaporation both the liquid and the vapor remain at the same temperature, but the vapor produced occupies a much greater volume than the liquid from which it was generated. Heat applied to vaporize serves only to separate the molecules of water from the relatively intimate contact in the liquid state to the greater distances existing in the vapor, forcing them apart against the confining pressure and against their own mutual attraction. *Dry steam* is water substance to which sufficient heat has been applied to just completely vaporize it. *Wet steam* or *saturated steam* is a mixture of dry steam and water, the latter existing in minute drops temporarily suspended in the vapor and more or less thoroughly mixed with it. It is produced either by partial condensation of steam originally dry or by too rapid generation in the boiler, the violent ebullition and foaming at the water surface projecting small particles of unevaporated liquid up into the vapor above. The vaporous portion of wet steam is exactly like dry steam; at the same pressure it has the same temperature and the same volume per pound; moreover, each pound has received the same quantity of heat and possesses just the same capacity for doing work as a pound of dry steam. But the water present has not received the large quantity of heat required to vaporize it, so that for work in a steam engine it is relatively inert. Its harmful effect in wasting heat in the engine is very much worse than its inertness would indicate, as will be explained later.

A quantity of dry steam enclosed in a tight receptacle would remain dry if no heat were taken from it, and would not change in temperature or pressure. If, however, heat were abstracted, some of the vapor would condense and probably collect in a thin film on the walls of the vessel. Meanwhile the temperature and pressure would decrease. But if a quantity of dry steam were held in a receptacle in open communication with a copious source of supply, such as the cylinder of a steam engine connected through the open port and pipes with a boiler, then if heat were removed from steam in the cylinder a partial condensation would result, collecting on the cylinder walls; but no appreciable loss in pressure or temperature would ensue, for the slightest diminution in pressure would bring more steam from the boiler. The total weight of water and vapor in the cylinder at any time could not be determined from the temperature, the pressure, or the volume occupied, but would depend also on what proportion of the whole contents was in liquid form. Heat may therefore be taken from or added to wet steam without changing its temperature or pressure; but the *quality*, or the decimal proportion (by weight) of dry vapor contained in the mixture is thereby altered, and the volume occupied by a given weight is changed. Therefore, neither temperature, pressure, nor volume, nor all three combined, give sufficient information to tell the proportion of live vapor in wet steam occupying a certain space or to ascertain the heat possessed by it, and, consequently, its capacity for doing work.

Careful experiments with saturated steam to determine the relation between pressure and temperature the heat required to produce one pound of vapor and the volume occupied by each pound have resulted in so-called *steam tables*. The following values are taken from Peabody's *Tables of the Properties of Saturated Steam*, a book recommended to the reader, though without a knowledge of thermodynamics certain of its columns will not be understood:

1	2	3	4	5	6
Absolute pressure in lbs. per sq. in.	Temperature Fahrenheit.	Heat in 1 lb. of liquid. q.	Heat of vaporization of 1 lb. r.	Total heat of 1 lb. of dry vapor. H.	Volume in cu. ft. of 1 lb. of dry vapor. s.
2	126.3	94.4	1026.1	1120.5	173.6
3	141.6	109.8	1015.3	1125.1	118.4
4	153.1	121.4	1007.2	1128.6	90.3
5	162.3	130.7	1000.8	1131.5	73.2
6	170.1	138.6	995.2	1133.8	61.7
15	213.0	181.8	965.1	1146.9	26.15
16	216.3	185.1	962.8	1147.9	24.59
17	219.4	188.3	960.6	1148.9	23.22
18	222.4	191.3	958.5	1149.8	22.00
19	225.2	194.1	956.6	1150.7	20.90
34	257.5	226.7	933.7	1160.4	12.07
35	259.2	228.4	932.6	1161.0	11.75
36	260.9	230.0	931.5	1161.5	11.45
37	262.5	231.7	930.3	1162.0	11.16
38	264.1	233.3	920.2	1162.5	10.88
77	309.2	278.7	897.5	1176.2	5.621
78	310.1	279.6	896.9	1176.5	5.554
79	310.9	280.5	896.3	1176.8	5.488
80	311.8	281.4	895.6	1177.0	5.425
81	312.7	282.3	895.0	1177.3	5.362
82	313.5	283.2	894.4	1177.6	5.301
83	314.4	284.1	893.7	1177.8	5.240
84	315.2	285.0	893.1	1178.1	5.182
85	316.0	285.8	892.5	1178.3	5.125
86	316.8	286.7	891.9	1178.6	5.069
87	317.7	287.5	891.3	1178.8	5.014
88	318.5	288.4	890.7	1179.1	4.961
89	319.3	289.2	890.1	1179.3	4.909
90	320.0	290.0	889.6	1179.6	4.858
91	320.8	290.8	889.0	1179.8	4.808
92	321.6	291.6	888.4	1180.0	4.760
93	322.4	292.4	887.9	1180.3	4.712
94	323.1	293.2	887.3	1180.5	4.665
95	323.9	294.0	886.7	1180.7	4.619

Pressures given are reckoned from an absolute vacuum, not from atmospheric pressure. Notice that as the temperature rises the pressure rises also. Under pressure of 90 pounds absolute per square inch (provided no air is present) steam cannot exist at less than 320° F, and except when separated from its liquid and superheated, which case will not be discussed here, it cannot be any hotter. The heat quantities given are in *British thermal units** per pound of water or of steam and are reckoned above 32° F. For instance, the quantity of heat necessary to warm a pound of water from 32° to 320.0° without evaporating any of it is 290.0 British thermal units, abbreviated B.t.u. This heat is held by the water and is called the heat above 32, per pound of liquid, or simply the *heat of the liquid,* and is represented by the letter q. After being warmed to 320° the further quantity of heat required to evaporate the entire pound under pressure of 90 pounds absolute per square inch is 889.6 B.t.u. This is called *the heat of vaporization.* The total heat required to warm the water from 32° and convert all of it into dry steam at 90 pounds pressure is therefore $290.0+889.6=1179.6$ B.t.u.; and this appears in column 5 represented by the letter H.

The volume tabulated is per pound of dry vapor. A pound of wet steam at 90 pounds would occupy less space. If its quality were .85, *i. e.,* if it contained 85 per cent of vapor, it would then consist of .85 pounds vapor and .15 pounds water. The vapor would occupy $.85\times4.858=4.129$ cubic feet, and the water $.15\times.017=.003$, so the volume of the whole would be $4.129+.003=4.132$ cubic feet. In general, if we know that the total weight of vapor and water present in a quantity of wet steam occupying V cubic feet is W pounds and that the pressure is p pounds absolute per square inch, we can find the quality of the mixture or the proportional weight of vapor present as follows:

$$V=W\,v=W\,(x\,s+(1-x)\,w)$$

in which v or $(x\,s+(1-x)\,w)$ is the volume of 1 pound of the

*A British thermal unit is the quantity of heat required to raise the temperature of one pound of water one degree, or, more exactly, to raise it from 62° to 63°, for the heat necessary per degree varies slightly at different temperatures.

mixture, $x\ s$ being the volume of the x pounds of vapor and $(1-x)w$ the volume of the $(1-x)$ pounds of water in each pound of mixture. w represents the volume of 1 pound of water, and for ordinary steam temperatures may be taken as .017 cubic feet with sufficient accuracy. The volume per pound of vapor, s, is given in the table. Solving the equation for x, the *quality,*

$$x=\left(\frac{V}{W}-w\right)\div(s-w)$$

Suppose that in the cylinder of a steam engine the indicator diagram shows at cut-off a pressure of 85 pounds absolute per square inch. Suppose also that at cut-off the volume between admission and exhaust valves, including clearance space and that portion of the cylinder up to the piston face, is 10.5 cubic feet, and that the total weight of vapor and water present in this space is 3.42 pounds, determined in a manner to be explained presently. The quantity of steam at that instant is

$$x=\left(\frac{10.5}{3.42}-.017\right)\div(5.125-.017)=.598,$$

since s for 85 pounds is 5.125 cubic feet. Unless the mixture is nearly all water its quality can be computed with sufficient accuracy by neglecting the small volume occupied by the water and assuming that the vapor present fills the entire space, thus: 3.42 pounds of dry vapor at 85 pounds absolute would occupy $3.42\times5.125=17.53$ cubic feet. The vapor in question occupies 10.5 cubic feet; therefore, only $\frac{10.5}{17.53}$, or .599 of the 3.42 pounds of substance is vapor. The rest is water. Let us say then that in this engine, at cut-off, 60 per cent of the "steam" is vapor and 40 per cent water. These figures represent with tolerable exactness the quality actually found in a simple engine. The condition indicated is, however, so different from what the average engineer supposes to exist that a more careful investigation will be worth while.

Fig. 45 is a card from the head-end of the high-pressure cylinder of a Corliss engine with piston 18 inches diameter and

36 inches stroke, running at 85 r.p.m. The piston displacement is $\left(\frac{18}{12}\right)^2\times.785\times\frac{36}{12}=5.30$ cubic feet. The *clearance* at the head end was measured by setting on the dead-point, closing the exhaust valve, and filling the cylinder and ports with water poured in through the admission port. It was found to be .47 cubic feet. If actual measurement were impossible it could perhaps have been calculated from dimensions taken from drawings of the engine, though in general this would probably be inaccurate, for cylinder heads are seldom of the exact shape shown on drawings and the

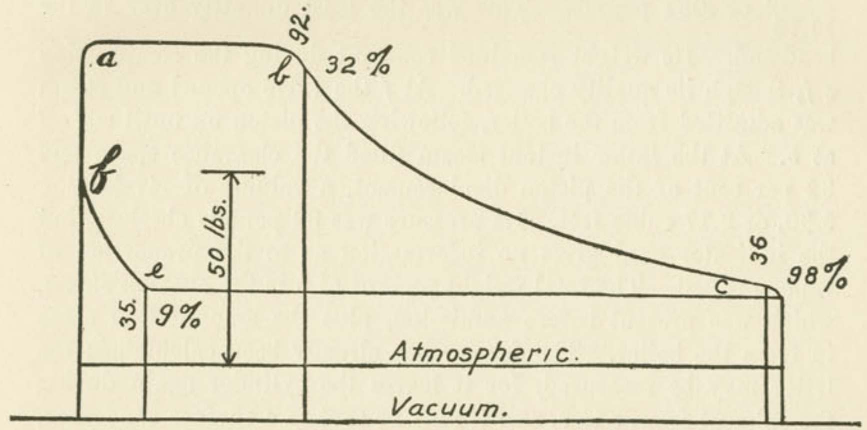


Fig. 45

linear clearance from the head to the piston is not likely to be precisely as designed.

On the card of Fig. 45 the vacuum line is drawn 14.6 pounds below atmospheric pressure, that corresponding to the barometer reading when the card was taken. Points b, c, and e, representing the events of cut-off release, and compression, were then determined by careful examination of the changes in curvature, and the horizontal distance of each from the head end was found in per cent of the full stroke and recorded as shown. The absolute pressure at each event measured from the vacuum line was also recorded.

On the return stroke at e the exhaust valve shut and no more steam could leave the cylinder. The small quantity caught and held within is called the *cushion steam.* At that instant it was under pressure of 35 pounds absolute per square inch and it filled the clearance space and part of the cylinder; that is, a volume of .47 cubic feet plus 9 per cent of the piston displacement or $.47+.09\times5.30$, making .95 cubic feet. Its weight can be computed if its quality is known. There is good evidence resulting from hundreds of elaborately conducted investigations showing that steam in an engine is practically dry at compression. A pound of dry steam at 35 pounds absolute occupies 11.75 cubic feet, as shown by the steam tables. The weight present at *e* then was $\frac{.95}{11.75}$, or .081 pounds. This was the least quantity ever in the head-end. Its weight remained constant during the compression *e f*, though its quality changed. At *f* the valve opened and steam was admitted from the boiler, following the piston up until cut off at *b*. At the latter instant steam filled the clearance space and 32 per cent of the piston displacement, a volume of $.47+.32\times5.30$, or 2.17 cubic feet. Its pressure was 92 pounds absolute, but the indicator card gives no information as to the proportion of vapor present. The total weight present at *b* is the *cushion steam*, which was present before admission, plus the amount that came in from the boiler. The former has already been calculated; the latter may be measured, for it leaves the cylinder again during the exhaust from *c* to *e*, and it may be sent to a surface condenser, reduced to water and weighed. When this card was taken 108 pounds were passing through the engine per minute, the same quantity, of course, going through first the high and then the low-pressure cylinder. To measure how much of it went through the head-end and how much through the crank-end, separate condensers would be necessary, and this is seldom possible. But the head and crank-end cards were almost exactly alike, so that we may assume that they received equal quantities of steam, and that $\frac{108}{85}\times\frac{1}{2}$, or .635 pounds entered and left the head-end per revolution. (A better method is to find from each card the *average pressure* at cut-off, release, etc., and the *average volume* occupied by steam at the different events in each end, and to use these values in connection with one-half the total quantity of steam in making the following computations.)

At cut-off, then, there was in the cylinder and clearance space $.635+.081=.716$ pounds of "steam," which word, loosely used, generally means wet steam or steam and water. The proportion of vapor present may be found by the equation on page 930, or by the approximate and shorter method which follows it. Thus: .716 pounds of dry vapor at 92 pounds absolute pressure would fill $.716\times4.760$ cubic feet$=3.41$ cubic feet (see table); the vapor present fills only 2.17 cubic feet. Therefore, only $\frac{2.17}{3.41}$, or 64 per cent of the "steam" in the cylinder is vapor; the rest is water.

Nothing escapes from the cylinder between cut-off and release. The weight of substance at *c* is then .716 pounds, and it fills the clearance space and 98 per cent of the piston displacement, or $.47+.98\times5.30=5.66$ cubic feet. Its pressure is 36 pounds, at which 1 pound of dry vapor would occupy 11.45 cubic feet and .716 pounds would fill 8.20 cubic feet; $\frac{5.66}{8.20}=.690$. Therefore the substance present in the cylinder at release is 69 per cent vapor and 31 per cent water.

These results give an idea of the changes in condition of steam during a revolution, which may be detected and studied by aid of the indicator diagram. Only a brief paragraph can be given to them here, though they are of great importance in the scientific design of steam engines. Steam practically dry, let us say, in the boiler, enters the engine cylinder at *f*, Fig. 45, and mingles with a small quantity already there. Contact with the relatively cold iron of the cylinder condenses part of it, for the metal is probably never as hot as the boiler steam nor as cold as the exhaust. This condensation on initial contact is so rapid that often more than half of all that has entered is condensed before quarter stroke is reached, the water formed collecting in a thin film on the iron surfaces. In the example calculated above, 36 per cent of the cylinder contents at cut-off had been reduced to the comparatively inert form of hot water. Its quantity is, of course, not enough to endanger the engine, but it has lost all its heat of vaporization, more than $\frac{3}{4}$ of all the heat it possessed, as will be realized by referring to the steam tables. It has parted with nearly all its power of doing work, and cannot regain that power until re-evaporated. Moreover, by condensing, it necessitates the entrance of more steam to sustain the pressure, thus increasing the steam consumption. Steam continues entering from *f* to *b*, but there is no method known by which the exact quantity in the cylinder at intermediate points, say between *a* and *b*, or at any other time when either the admission or exhaust valve is open, can be determined. After cut-off, however, the quantity present can be found as explained, and the per cent of vapor determined for any time during expansion, but not after the exhaust begins. Part of the steam condensed during admission is re-evaporated during expansion, because the mean temperature of the iron is hotter than steam at the lower pressures. Re-evaporation continues during exhaust while steam is leaving the cylinder, most of the water remaining at *c* being re-converted into vapor before the exhaust valve shuts. Re-evaporation would be of good service because it tends to sustain the pressure during expansion, yet does not perceptibly change the back pressure; but, unfortunately, the heat required for it is taken from the cylinder, reducing the temperature of the iron and so augmenting the initial condensation between *f* and *b* on the next stroke.

This interchange of heat between steam and the cylinder walls is by far the greatest cause of wastefulness in the steam engine. Watt discovered it more than a century ago, and reduced it by inventing the separate condenser. Modern inventions, including the steam jacket, the use of superheated steam and compound and multiple-expansion engines, have cut it down still further, and the indicator has been useful in studying their action as well as measuring the gain due to them. But initial condensation and subsequent re-evaporation still remain the chief causes of poor economy.

Engine Tests. Tests of steam engines are usually made to determine the cost of producing power. The brake horse-power, or power delivered by the engine shaft, is seldom obtainable except for small engines, and then only under favorable conditions; hence the indicated horse-power is measured from the cards and allowance output at the shaft. Cost per horse-power is generally reckoned in terms of the weight of steam used or the heat used per hour. If all engines were supplied with steam of the same quality, at the same pressure, and if all exhausted against equal back pressure, the quantity used per horse-power-hour would be a satisfactory criterion for comparing their economy. But of two engines developing equal power and operating under conditions otherwise alike, except that one uses high and the other low-pressure steam, both using the same quantity, the former is surely less economical. It costs more

to make high- than low-pressure steam, because the former contains more heat per pound, and other conditions being the same, more coal must be burned to produce it. Again, of two engines developing equal power, receiving steam of the same pressure and quality, consuming equal quantities per hour and operating under conditions otherwise alike, except that one exhausts at lower pressure than the other, the first has the poorer economy, partly because of the cost of maintaining a low exhaust pressure and partly because the temperature of the exhaust is lower. Exhaust steam, under suitable conditions, can be condensed and returned to the boiler as feed water with slight loss in temperature. When returned relatively cold it requires more heat and the combustion of more fuel to change it again into steam. It is therefore apparent that the mere quantity of steam used does not indicate the economy.

A scientific measure for comparing economy resulting from different engine tests is the heat used per horse-power per hour.

Suppose an engine is supplied with dry steam of 95 pounds absolute pressure, that the temperature in its exhaust pipe is 126.3° F, and that steam exhausted, after being condensed, is finally pumped back into the boiler at 90 F. The heat in each pound arriving at the throttle is 1180.7 British thermal units, as given in the steam tables. Each pound leaving the cylinder possesses an unknown quantity of heat, because it is part water and part vapor in unknown proportions. If condensed in a surface condenser, it will issue from the air pump discharge several degrees colder than 126.3, depending on various conditions. Suppose it issues at 110°, and then goes to a receiving tank or *hot well,* where it unavoidably cools to 90°, and finally is returned to the boiler as water at that temperature. A pound of water at 90° contains 58.0 B.t.u. (not given in the table). When evaporated into dry steam at 95 pounds, it will contain 1180.7; the difference, or 1122.7 B.t.u., must be supplied by the boiler. If the exhaust steam had been condensed very slowly in a specially arranged condenser, it might, theoretically, at least, have been reduced to water without further loss in temperature and been pumped back to the boiler at 126.3. Then it would have possessed 94.4 B.t.u., and would have required an addition of only 1180.7—94.4, or 1086.3 instead of 1122.7 to heat and evaporate it. If the test is to show the economy of the engine alone without auxiliaries, should it be charged with 1122.7, or 1086.3 B.t.u. per pound of steam used? Evidently the latter, for the engine should not be debited with heat lost by an inefficient condenser and subsequent cooling before returning to the boiler. The heat used per pound of steam should be the difference between that contained when arriving at the throttle and that of water at the temperature in the exhaust pipe. The quantity of steam should include only that used by the engine itself without auxiliaries. Therefore, if 10,000 pounds of steam were used per hour and 400 indicated horse-power developed the steam consumption would be $\frac{10000}{400}$, or 25 pounds per I.H.P per hour, and the heat consumption 25×1086.3, or 27,200. B.t.u. per I.H.P. per hour to the nearest third significant figure. If the engine were jacketed with steam at full boiler pressure, condensation from the jackets could be trapped out as water at full boiler temperature, 323.9°, (see table), and returned to the boiler with but slight loss, theoretically with no loss. Each pound returned would contain 294.0 B.t.u., the heat of the liquid at 323.9°. To re-evaporate it would take 1180.7—294.0=886.7 B.t.u. Supposing the jackets used 500 pounds per hour, the total consumption of the engine per indicated horse-power per hour would be $25+\frac{500}{400}=26.3$ pounds, and the total heat consumption $27{,}200+\frac{886.7\times 500}{400}=28{,}300.$ B.t.u. per I.H.P. per hour.

On the other hand, if the test is for economy of the entire power plant, to show the total cost in steam or in heat required per unit of its product, that is, per horse-power developed, then the engine should be debited with all the steam and all the heat used or wasted by itself and its auxiliaries, including the air pump, circulating pump, and feed pump, with all piping and drips from the throttle valve to the boiler. It should be credited with only the useful output, viz.: its brake horse-power; but as this cannot often be measured directly, the indicated power may be used instead.

Suppose the following data result from a plant test:

Indicated horse-power of main engine..........1300
Steam condensed and weighed after passing through cylinders of main engine..........21,600. pounds per hour
Barometer 29.8 inches. Atmospheric pressure..........14.6 pounds
Pressure at throttle, 78.4 lbs. gage, or 93.0 lbs. absolute.
Steam at throttle contained 1% moisture.
Temperature in exhaust pipe..........141.6° F
Jackets supplied with steam taken from main steam pipe near throttle. Ordinarily, water condensed in them was returned to boiler (not through feed pump) at 320.0°. During test it was drained into weighing tanks showing 1350 pounds per hour.
Dry steam at 62.4 pounds gage pressure or 77.0 pounds absolute supplied to combined air and circulating pump and to feed pump. Exhaust from pumps used to heat feed-water, and not returned to boiler.
Consumption of air and circulating pump..........1160. pounds per hour
Consumption of feed pump..........940 pounds per hour.
Temperature of feed water at boiler..........170°

The total steam consumption of the plant was

$$\frac{21600+1350+1160+940}{1300}$$

or 19.3 pounds per I.H.P. per hour.

Each pound arriving at the throttle was at 322.4°, and was only .99 vapor, so it contained as much heat as 1 pound of water at 322.4° and .99 of the heat required to vaporize one pound at that temperature; that is, $292.4+.99\times 887.9$, or 1171.4 B.t.u. Each pound of water fed to the boilers at 170° contained 138.5 B.t.u. Each pound returned from jackets at 320° contained 290.0 B.t.u. The heat consumption of the main engine was therefore

$$\frac{21600\ (1171.4-138.5)+1350\ (1171.4-290.0)}{1300}=18{,}100 \text{ B.t.u.}$$

per I.H.P. per hour

The pumps received dry steam at 77.0 pounds absolute, containing 1176.2 B.t.u. per pound. When exhausted, after passing through the feed heater, this steam was thrown away, but for every pound another pound, taken from some fresh water supply, was warmed and fed to the boiler at 170°, containing 138.5 B.t.u. The heat required for operating the pumps was (1160+940) (1176.2—138.5)=2,180,000 B.t.u. per hour, or $\frac{2,180,000}{1300}$ =1,680 B.t.u. per I.H.P. of main engine per hour.

The total cost in heat units for each indicated horse-power developed by the main engine was therefore 18,100+1,680 or 19,800 B.t.u. per hour, and this was furnished by coal burned under the boiler.

In testing for economy, steam used by the main engine, jackets, pumps, etc., should always be measured as directly and exactly as possible either by condensing the exhaust in a surface condenser and then weighing it, or by carefully weighing all water fed to the boiler and deducting quantities used for other purposes. For specific instructions and advice on this subject the student is referred to the standard system of testing steam engines recommended by the American Society of Mechanical Engineers and published in their *Transactions, Vol. XXIII.*

Sometimes the indicator diagram is used to furnish data for calculating the quantity of steam passing through an engine cylinder per revolution, and thus for determining the steam consumption per hour. Pressure at compression and release are measured as in Fig. 45, and the volume occupied by steam at each of these instants is computed from measurements of the diagram and dimensions of the engine. Assumption is then made that the substance present in the cylinder at these times is dry steam, and its weight is calculated accordingly. The weight thus found at release minus that retained at compression is then taken as the *steam consumption per stroke as accounted for by the indicator diagram.* But though, as has been stated, the cylinder contents are almost always approximately dry at compression, they are not at release. The quality of steam at release depends on how wet it was originally, where the cut-off takes place, how much it expands, whether or not a jacket is used, how large the engine is and how fast it runs, and on other factors so difficult to allow for mathematically, that no calculation can accurately predict the quality which will actually be found by such a computation as given. For the card of Fig. 45 the "steam" at release was really 31 per cent water. If it were assumed dry and the calculation for steam

used per stroke were carried out as stated, the result would be about 35 per cent less than the true weight found by actual measurement. A calculation which leads to such an error is of course absolutely worthless. The steam used per stroke or per hour should be determined only by actually measuring it, after which it may be used to calculate the degree of wetness resulting from the above-mentioned case; but the converse calculation, assuming data probably incorrect, is a mere waste of time.

Locomotive Reducing Motions. When taking indicator cards for a locomotive it is quite important, as in other types of engines, to have the proper reducing motion. An indicator provided with

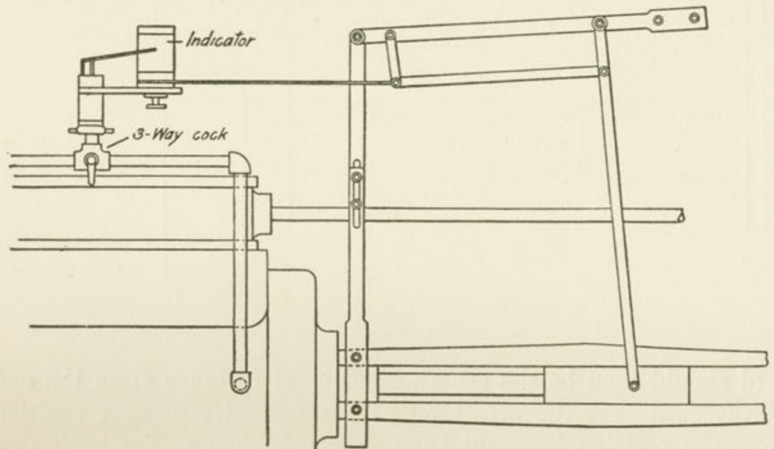


Fig. 46.

a reducing wheel, as shown in Fig. 28, is perhaps as good a reducing motion as can be used on a locomotive, but Figs. 46 and 47 show two arrangements which may be used to good advantage where a reducing wheel is not obtainable. The precautions which must be taken when constructing a reducing motion of this kind are to always have the arms of the indicator cards parallel to each other and the point to which the indicator string is attached must always be in a straight line with the fixed point of the indicator motion and the moving point on the crosshead. In this way the motion of the indicator will be exactly in proportion to the movement of the crosshead. It is always advisable before taking indicator cards to test the accuracy of the indicator motion. This may be done by stopping the engine at different parts of the stroke, measuring the distance that the crosshead is from the end of the stroke, and at the same time making a pencil mark on the indicator card by moving pencil up and down. The line on the indicator

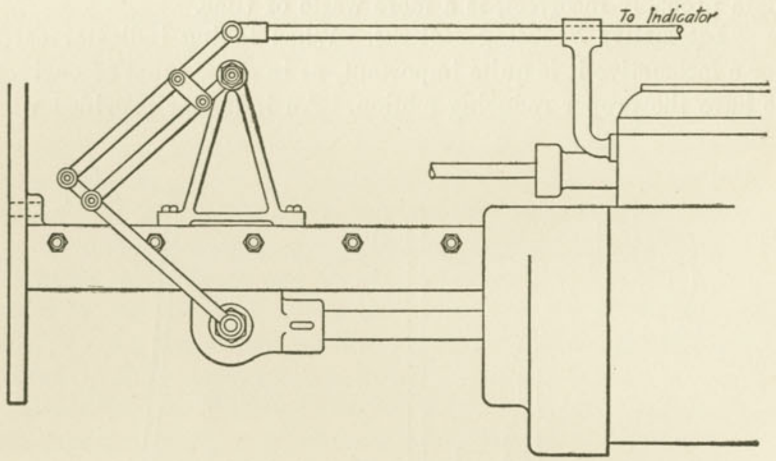


Fig. 47.

card should then be the same proportional distance from the end of the card that the crosshead pin is from its present position from the position it would have occupied when at the beginning of the stroke. Various lines can thus be drawn on the indicator card to represent various positions of the crosshead, and if the indicator motion is correct the position of these lines should always bear the same relation to each other that the different positions of the crosshead do.

REVIEW QUESTIONS.

THE STEAM ENGINE INDICATOR.

1. Give a complete definition of the term *mean effective pressure* as applied to a steam engine.

2. Draw a card such as would be obtained from a Corliss engine having all events of the stroke too early. What change in the valve-gear should be made to correct the errors indicated by such a diagram?

3. What is the *engine constant* or *horse-power constant* used in computing indicated power?

4. Sketch and dimension a Brumbo pulley reducing rig to give a card of proper length when used with an engine of 48-inch stroke at 75 r.p.m.

5. What change would be advisable in the above rig to adapt it to an engine of 20-inch stroke?

6. What is meant by "a 50-pound spring" for an indicator?

7. What objection would there be to using a 100-pound spring in the low-pressure indicator for a compound condensing engine where the receiver pressure is 20 pounds?

8. Calculate the horse-power constants for a 24x36 inch engine having a $3\frac{1}{2}$-inch piston rod.

9. If the above engine runs at 125 r.p.m. and develops an M.e.p. of 21.4 pounds in the head-end and 22.6 in the crank-end, what is its indicated horse-power?

10. What effect does inertia of the indicator drum have on the length of the diagram?

11. How and why was the atmospheric line of Figs. 40 and 42 drawn as shown?

12. When the barometer reads 29.5 inches, what is the atmospheric pressure per square inch?

13. If two diagrams, one like H, Fig. 8, the other like Fig. 42, were shown you, how could you distinguish the steam engine card from the compressor card?

14. What is the *brake horse-power* of an engine? Why is it greater than the indicated horse-power?

15. What change should be made in the valve-gear to correct the faults shown by Fig. 24?

16. If a diagram from a pump, like Fig. 43, but withont any arrows, were shown you, how would you tell in which direction it was drawn?

17. The back pressure line of Fig. 24 apparently coincides with the atmospheric line. How could the indicator be arranged to detect slight differences between them?

18. It is desired to draw the vacuum line on a diagram taken when the barometer read 31.1 inches. A 16-pound spring was used. How far below the atmospheric line should the vacuum line be drawn?

19. A weight of 1000 pounds is to be hoisted 1200 feet in 4 minutes. What horse-power is required for the actual work of hoisting? Would an engine having 10 indicated horse-power maximum capacity be sufficient for the work?

20. Cards from a 10x12 inch engine running at 320 r.p.m. show the following mean effective pressures: head-end 46.0; crank-end 41.5. The piston rod is 2 inches in diameter. What is the indicated horse-power?

21. Before attaching an indicator to a new engine or to one just fitted with new piping, what precautions should be taken to protect the indicator from scale and grit?

22. An Otto gas engine 11¼x18 inches runs at 228 r.p.m. A card taken from it at full load is shown in Fig. 37. What is its indicated horse-power?

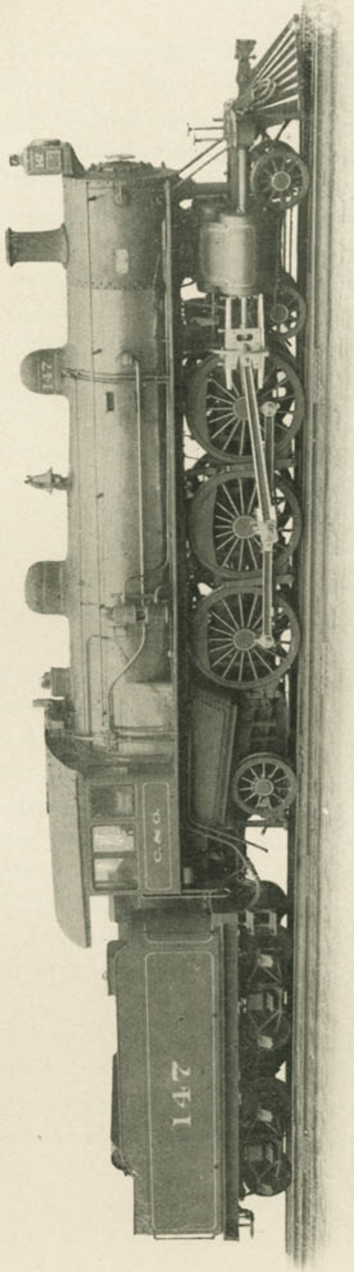
23. What causes the vibration shown by the diagram of Fig. 38? How would you planimeter such a diagram?

24. A steam engine drives a main shaft which transmits power to three different mills by means of separate belts. How could the power required to run each mill be measured? To what errors would the results be liable?

25. The area of an indicator card taken with a 100-pound spring is 2.05 square inches. Its length is 3.20 inches. What is the M.e.p.?

26. In a looped diagram like Fig. 16, how do you decide in which direction to run the planimeter for measuring the net area?

27. If an indicator diagram lies entirely below the atmospheric line, how is the mean effective pressure affected?



PACIFIC TYPE OF LOCOMOTIVE USED ON THE CHESAPEAKE & OHIO RAILROAD
(American Locomotive Company)

Engine Parts and Running Gear

The steam which is generated in the boiler enters the steam chest of the cylinder by way of the main throttle-valve, dry pipe and steam pipe. From the steam chest it passes through the admission port into one end of the cylinder and forces the piston to the opposite end of the cylinder, and, after having done its work in the cylinder, the steam passes through the exhaust pipe into the atmosphere.

The pressure of steam on the piston is transmitted to the piston rod, connecting rod and crank pin, which, being connected to the wheel some distance from its center, causes it to rotate and the locomotive to move.

The arrangement of valves and eccentrics for properly operating the valves is taken up under the subject of valves and valve gears, and the arrangement of the steam and exhaust pipes is explained in connection with the locomotive boiler. It will be the object of this chapter to explain the construction and design of the cylinders, pistons, piston rods, stuffing-boxes, crosshead and locomotive running gear with which the reciprocating parts of a locomotive are connected.

The simple locomotive consists of two engines, one on each side of the locomotive. These engines are connected to the same shaft upon which the crank pins are located, at right angles to one another. The crank pins are arranged in this manner for the purpose of preventing the engine from becoming stalled on dead center, because when one crank pin is on dead center the other is at right angles to the center line of the cylinder, which is the best position for transmitting the linear motion of the piston into rotary motion of the driving wheels.

The steam which enters the cylinder either follows the piston at full boiler pressure or is cut off before the piston reaches the end of the stroke. When steam is cut off before the end of the stroke is reached the steam is said to be used expansively, in which case the energy in the steam is used for moving the piston between the time of cut-off and release.

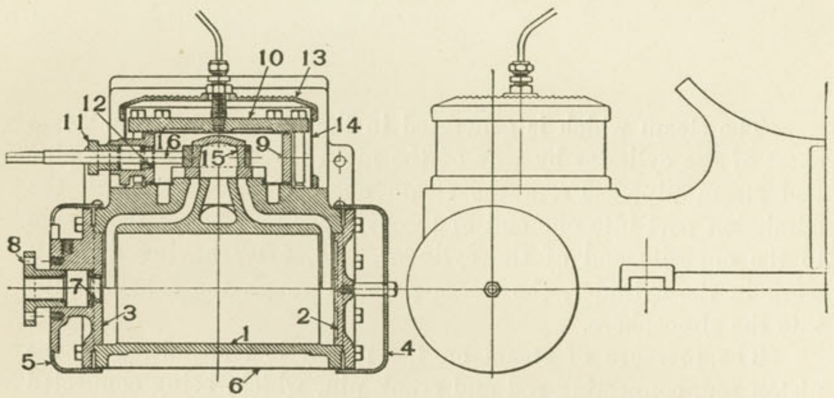


Fig. 1.

SECTION OF ENGINE CYLINDER.

Cylinder. The cylinders of a locomotive, in which the work of the steam in moving the train is accomplished, are made of uniform, close-grained, hard cast iron. The iron must be hard enough to resist abrasion, and it must be soft enough to allow the interior of the cylinder to be bored, the ends of the cylinder turned off, the valve seats planed, and the bolt holes for the cylinder covers bored. The steam and exhaust ports and valve seats are cast with the cylinder to avoid joints. The valve chest may be located either on the top or at the sides of the steam cylinder, and may be either circular or rectangular in shape.

Parts of an Engine Cylinder. The arrangement of the different parts of an engine cylinder is shown in Fig. 1. 1 is the cylinder itself; 2, the front cylinder head; 3, the back cylinder head; 4, the front cylinder head casing; 5, the back cylinder casing; 7, piston rod stuffing-box ring; 8, piston rod stuffing-box gland; 9, steam chest; 10, steam chest cover; 11, valve stem gland; 12, valve stem stuffing-box ring; 13, steam chest cover casing; 14, steam chest casing; 15, steam chest valve; 16, steam chest valve yoke.

Sizes of Cylinders. The securing of the proper proportions of cylinders for a locomotive is a matter of great importance in locomotive designing. They must be large enough so that with the maximum steam pressure of the boiler they can always turn the driving wheels when the locomotive is starting, but their size should not be much greater than that needed for that purpose, otherwise the pressure on the pistons will be apt to slip the wheels on the rails. The maximum force of the cylinders should, therefore, be equal to the adhesion of the wheels to the rails. This may be assumed to be equal to one-quarter of the weight on the driving wheels. The maximum mean effective piston pressure may be taken to be 90 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, the determination of the size of the cylinder usually consists in a calculation of its diameter. In order to make this calculation, the diameter of the driving wheels, the weight on the driving wheels, 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:

Divide the weight on the driving wheels by four, which gives the adhesion, and multiply by the circumference of the driving wheels. This gives the amount of work that the wheels are capable of transmitting in one revolution. Then multiply 90 per cent of the boiler pressure, or the maximum mean effective pressure on the piston, by four times the stroke of the piston, or the total distance traveled by the two pistons in one revolution of the wheels. Divide the work that the wheels are capable of transmitting by total distance traversed, and the quotient will be the area of each piston in square inches.

Putting the above rule in the shape of a formula, we have:

$$A=\frac{\frac{W\times C}{4}}{.90\ P\times 4S}=\frac{W\times C}{14.4\ P\times S}$$

or

$$A=\frac{W\times D\times 3.1416}{14.4\ P\times S}=\frac{.218\ W\times D}{P\times S}$$

in which

A=area of each piston in square inches.
W=weight on driving wheels.
C=Circumference of driving wheels=3.1416 D.
D=diameter of driving wheels in inches.
P=boiler pressure in pounds per square inch.
S=stroke of piston in inches.

In order to make a practical application of this rule, let us take an engine in which the weight on the driving wheels is 95,000 pounds; the diameter of the driving wheels is 62 inches; the boiler pressure 180 pounds per square inch, and the piston stroke is 24 inches. The last formula then becomes:

$$A=\frac{.218\times 95{,}000\times 62}{180\times 24}=297.2\text{ sq. in.}$$

or the diameter of the cylinder should be 19.44 inches. Such a cylinder would in practice probably be made 19 inches in diameter.

Counterbore. As will be noticed in Fig. 1, which represents a section of an engine cylinder, the cylinder at its two ends is slightly larger than the standard diameter through the rest of its length. This enlargement is called the counterbore, and is used for three reasons: 1, to prevent the piston and its rings from wearing a shoulder at each end of the stroke, which would cause a pound or knock if the engine were keyed up; 2, the enlargement simplifies the operation of getting in the packing rings; 3,

in case the cylinder requires reboring, it gives a perfect cylinder from which to work.

Cylinder Cocks. To drain the cylinder and to get rid of excessive water of condensation, a hole is drilled in each counterbore at the lowest point of the cylinder. These openings are controlled by valves called cylinder cocks, which are opened when the cylinder is too warm at starting, because, when the engine is not working, the cylinders and steam pipes are cooled off, so that when steam is led into them a considerable portion is condensed until they become warmed. Water is also frequently carried over

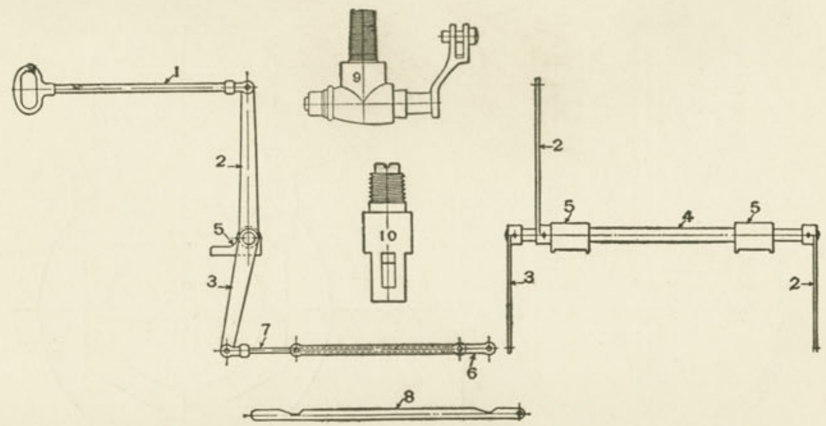


Fig. 2.

Cylinder Cocks and Rigging.

from the boiler with the steam. This water collects in the bottom of the cylinders, and will not escape through the exhaust pipes until the piston forces it out near the end of the stroke. The water, however, will flow out so much more slowly than the piston moves that there is great danger of knocking out the cylinder head unless there are other means of relief. The cylinder cocks are, therefore, placed in the under side of the cylinder, so that when they are opened, when the engine is starting, or when there is any indication that there is water in the cylinder, the water will escape through them. These cocks are usually opened and closed by means of rods, which connect with valve handles on one end, and a vertical arm on the other, which is operated in the cab, so that they can be opened and closed by the engineer whenever necessary. Fig. 2 shows two forms of cylinder cocks and rigging which are used, in which 9 represents one form of cock, and 10 represents another. The rigging for opening and closing the valve consists of: 1, cylinder cock operating rod; 2 and 3, cylinder cock shaft arms; 4, cylinder cock shaft; 5, cylinder cock shaft bearing; 6, 7 and 8, cylinder cock coupling rods.

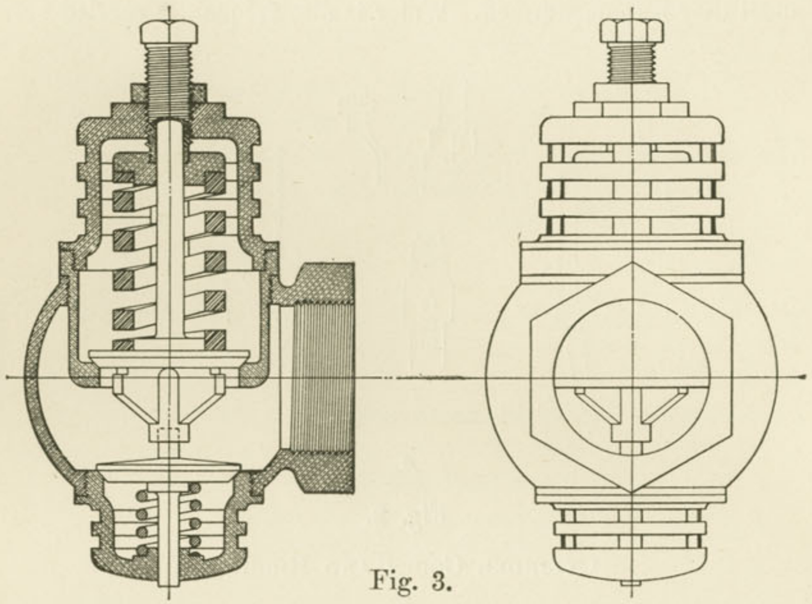


Fig. 3.

CYLINDER RELIEF VALVE.

Instead of being operated by rods, cylinder cocks are often operated by air. These pneumatic cocks consist of a small cylinder with a piston under each valve, which is moved by an operating valve in the cab. Air is admitted to the cocks when the operating lever is opened, which either opens or closes them as desired. The piping consists of ¼-in. pipe, and the air is obtained from the main air reservoir.

Relief Valves. Combined pressure and vacuum relief valves are placed on low-pressure steam chests of compound engines, and

single-pressure relief valves are placed in the cylinder heads, which are arranged to open in cases of emergency. These valves are usually plain conical valves, opening outward, and held in place by a coiled or flat spring. The tension of the spring is made greater than the usual steam pressure, so that under normal conditions the valves remain on their seats. Excessive pressure from any cause lifts them off their seats, and relieves the cylinder and the cylinder cover. Fig. 3 shows a relief valve used on cylinder

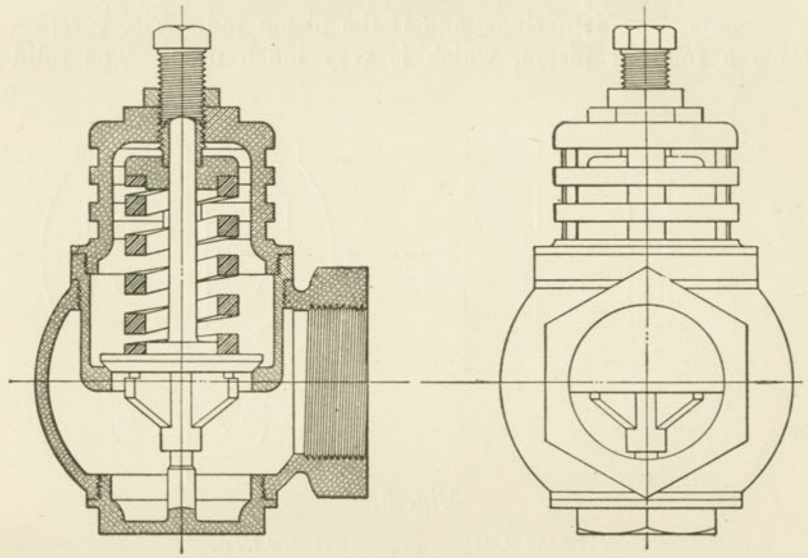


Fig. 4.

COMBINED RELIEF AND VACUUM VALVE.

heads, Fig. 4 represents a combined relief and vacuum valve used on low-pressure cylinders, and Fig. 5 represents a vacuum valve used on low-pressure cylinders.

Cylinder Lagging. The radiation of heat from the cylinder must be reduced as much as possible so as to prevent waste of the steam due to condensation. For this purpose, hair felt, mineral wool, asbestos or wood, or a combination of these with asbestos boards are used. This is called the cylinder lagging, and the outside cover is called the cylinder casing. This is shown at 6 in Fig. 1.

Pistons. The piston, which drives the reciprocating parts of the engine, must be so made as to fit the bore of the cylinder steam-tight, and it must be so designed as to carry the piston rod to which it is attached. It is made in various designs, shown in Figs. 6, 7 and 8. Fig. 6 represents a box piston with a solid head. The two faces of the piston are of solid metal, but the spaces between them, A, A, are made hollow so as to reduce the weight. The hole, D, is tapped in the end of the piston, in order to take out the core sand. It is plugged shut when in use. B represents the piston rings, and C the piston rod. Fig. 7 represents a follower piston, which is very much used. The solid

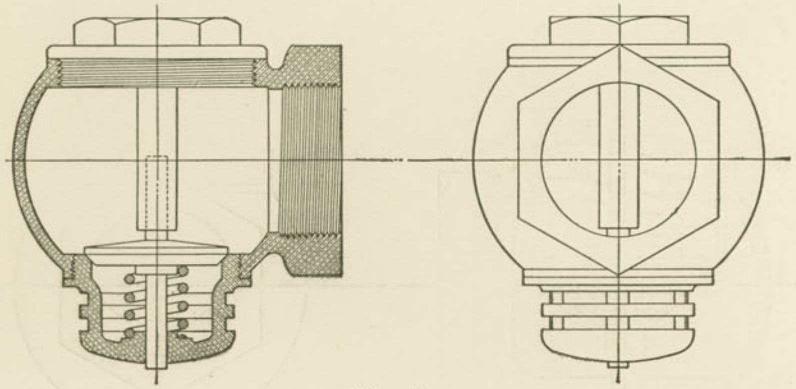


Fig. 5.

Steam Chest Vacuum Valve.

part, called the spider, is shown at A, which constitutes one face of the piston rod. The other face of the piston is a separate plate, B, which is bolted to the spider by means of follower bolt, F, and forms the cover. The piston rod E passes through the spider, and is either riveted over after being keyed to the spider, or is fastened on with a nut and lock nut. Fig. 8 shows an approved construction of piston and rod. The body of the piston P is a steel casting of the dished type. To this is bolted the rim R, made of cast iron. At the bottom the rim may be widened as at OO, so as to secure a greater wearing surface. Two grooves are cut in the rim, and into these are sprung the two rings, K, K. These rings are held out against the walls of the cylinder by

their own resilience. Steam is prevented from leaking past the joint where they are split by a cap, as shown at the bottom. The piston rod A is made of steel, and is held in the piston by the nut N, which draws the rod tightly into the taper fit in the piston. At the cross-head end the taper seat B is drawn tightly into the cross-head by a key.

Piston Packings. Since the piston cannot ordinarily be fitted to its bore so as to be steam-tight, some provision must be made to maintain a steam-tight joint. There are various methods which may be used for doing this, but the most usual method of making a piston steam-tight is by means of rings, which fit in grooves turned in the bearing surface of the piston. These

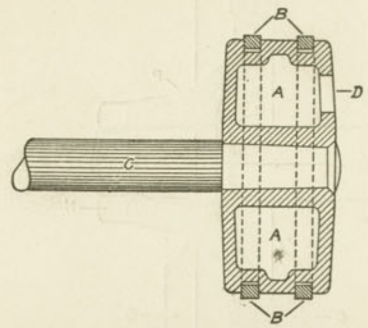


Fig. 6.

Box Piston.

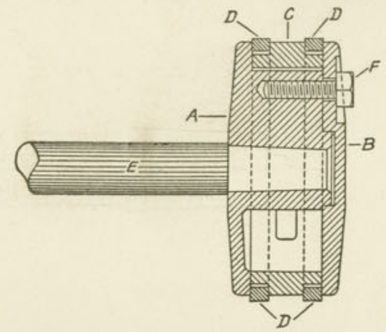


Fig. 7.

Follower Piston.

rings should fit the grooves on their sides tight enough to prevent leakage, and they must be forced radially outward with sufficient force to prevent steam leakage between them and the bore. Such rings are called piston packing rings, and they differ in design according to the design of the piston. The piston rings, in order to be elastic, must have a break in them in some part of their circumference, so that their length may vary, and the joint between the two ends must be made so that the steam will not leak past it. The joint is made steam-tight by making a scarf joint, or by fitting a tongue piece in both ends of the ring, which will close the joint. It is usual to have two or more rings, so that the joints in the rings will not come into line, which will also prevent leakage.

Snap Rings. There are various methods used for forcing the piston rings out against the cylinder. The one most generally used depends upon the elasticity of the ring itself. The ring is generally made of cast iron, and is turned as a solid ring to fit a diameter larger than the bore. Usually the proportion is a quarter of an inch larger for each foot of diameter. The finished ring is then sawed apart and sufficient metal taken out to permit the ring to be squeezed together so as to enter the cylinder. It will tend to expand to its original size against the bore, and this pressure makes it steam-tight. Such rings are called snap rings,

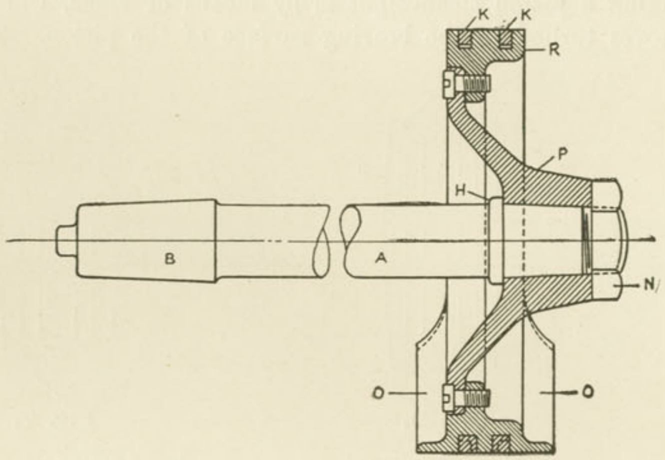


Fig. 8.

DISHED PISTON.

and in order that the radial pressure of the ring may be the same all around the circumference, the thickness of ring should be different at different distances from the joint. With the type of solid piston shown in Fig. 6, snap rings as shown at B, B, must be used.

With follower pistons the packing rings can either be of the form mentioned above, or they may be made so that the packing rings are pressed out with springs or adjustable bolts. In some cases steam is allowed to enter under the ring, so that it will press out against the bore and keep the joint steam-tight. With the type of piston shown in Fig. 7, the packing rings, D, D,

move in grooves cut in the bull ring C, which is made solid. The weight of the piston causes this ring to bear on the bottom of the cylinder, so that if the joints in the snap ring are put at the bottom there will not be much tendency to leak past them.

Piston Rods. The piston rod must transmit the motion of the piston to the mechanism outside of the cylinder, and must be able to withstand the tendency to wear out of round where it passes through the cylinder head and its stuffing-box. Piston rods are, therefore, generally made of cold-rolled steel, which gives a hard and close fibre suitable for this purpose. Piston rods may be secured to the piston by being screwed into it and riveted over, being fitted to a straight or tapered hole in the piston, and fastened either with a key or nut, or riveted over, or the piston may be shrunk on the rod.

The other end of the piston rod must be connected to the cross-head. This is usually done by making the end of the piston rod fit a tapered hole in the cross-head, which is held tight by means of a transverse key.

In calculating the strength of the piston rod it may be considered as a solid circular column, with a length equal to the distance from the cross-head to the piston, which is called upon to carry a load equal to the total steam pressure on the piston. The diameter of the piston rod may be calculated by the following formula:

$$A=\frac{B}{S}+\frac{P\,C\,L^2}{S\,D^2}$$

in which

A=area of metal in square inches.
B=breaking strength of column.
S=working strength of the metal.

$$D=\frac{d^2}{16}$$

d=diameter of piston rod.
C=a constant.
L=length of rod in inches.

As the load is not a static one, and as the piston rod is subjected to very severe jars and shocks, an exceedingly high factor of safety should be allowed.

Stuffing-box. The hole through which the piston rod passes through the cylinder head must be made steam-tight, and to do this special devices, known as stuffing-boxes, must be used. A typical stuffing-box is shown in Fig. 9, where A is the stuffing-box; B, the stuffing-box gland; D and E, bushings, which can be replaced in case of wear; C, stud bolts; N, N, the stud bolt nuts, and P, the piston rod.

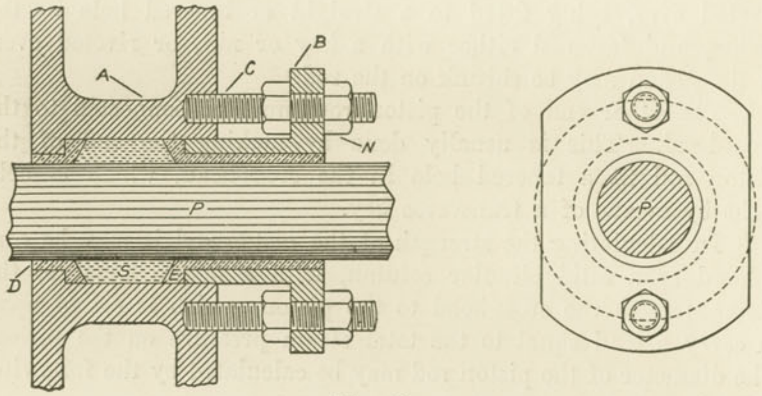


Fig. 9.

STUFFING BOX.

The piston must be surrounded with some form of adjustable and elastic material, which will permit the rod to pass in and out with the least friction, and which shall seize it tightly enough to prevent leakage of steam and water from the steam. The packing goes in the space S, and the gland B compresses it into its place. Bushings are usually provided for, as shown at D and E, because if there is any wear around the rod the bushing can be forced out and replaced with a new one. These bushings are made to taper inward toward the rod, because when the gland is compressed the pressure of the packing will be inward upon the rod. The gland is usually drawn inward by means of two bolts, N, N. For large rods, four bolts are sometimes used

for moving the gland, in order that the same pressure may be exerted around the circumference of the packing.

For small rods, such as valve stems, the outside of the stuffing-box, instead of being formed into a flange, is often threaded, and a hollow nut fitting over the gland will draw the latter inward when screwed upon this stuffing-box thread.

Packing Material. The requirements of a packing material, which may be used in a stuffing-box, are elasticity, low friction,

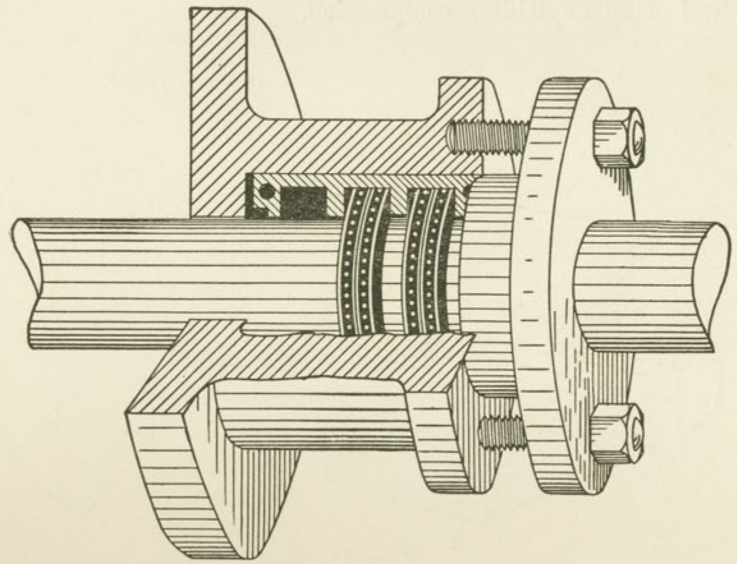


Fig. 10.

HOLMES METALLIC PACKING.

absence of abrasive effect upon the rod and capacity to prevent and absorb leakage. Soft packings, which are made of rubber, hemp, cotton, asbestos, flax, paper fibre, etc., have been widely used. The rubber gives elasticity, and the other material the quality of absorbing and holding the lubricant. Packings of this class are laid in the stuffing-box in a spiral coil, and are compressed by the gland.

On account of the high temperature and hard service which locomotive piston packings must endure, the use of soft packings makes it necessary to renew them frequently, and for the purpose of making a mechanical method of packing, which will last longer and resist both heat and pressure, a large variety of metallic packings are made. The principle of such packings is to have a series of split rings, whose surfaces slope alternately from and toward the rod, so that when endwise compression is exerted by the gland they close inward upon it. Sometimes a coiled spring is introduced either behind the gland or around the packing rings, so that the compression of the split rings may be an elastic force instead of an unyielding compression.

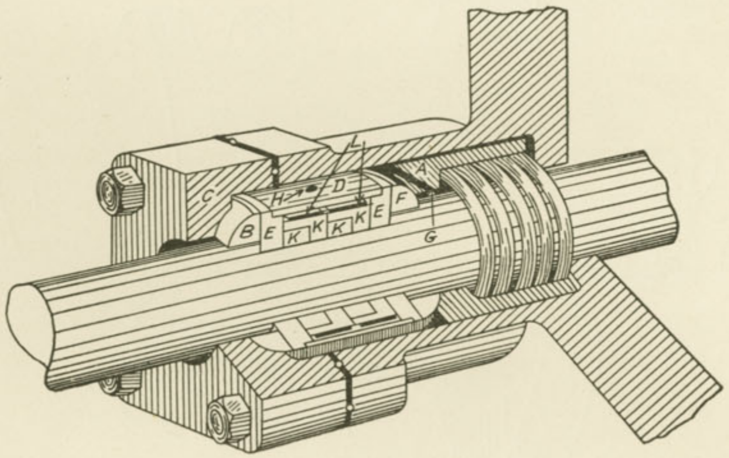


Fig. 11.

TROJAN METALLIC PACKING.

One form of metallic packing which has had wide use on locomotives is the Holmes metallic packing, shown in Fig. 10. The packing is contained in a metal case cut in half, which case is made to fit the stuffing-box. The packing rings are made of cast iron, and are split so that the coiled springs around the circumference can take up the wear and uneven portions of the rod. After the rings are placed in the case, the case is inserted in the stuffing-box, and a joint of lead or one ring of asbestos is placed in the bottom of the stuffing-box. All the different forms of pack-

ing which are used to pack piston rods are used to pack valve stems.

Another form of metallic packing is shown in Fig. 11, and is known as the Trojan. The packing rings K are enclosed in a vibrating case formed by the discs E and the casing D, and are a free fit between disc E, without having any lost motion between these discs. The ball ring B is ground to the gland C, making a steam-tight joint. The outer disc E makes a steam-tight joint with B. The ports G and H admit steam to the interior of the casing D, in order to press the rings against the rod. The follower A fits freely in the stuffing-box, and the spring holds the parts in position. Band springs L hold the sections of the soft metal ring together.

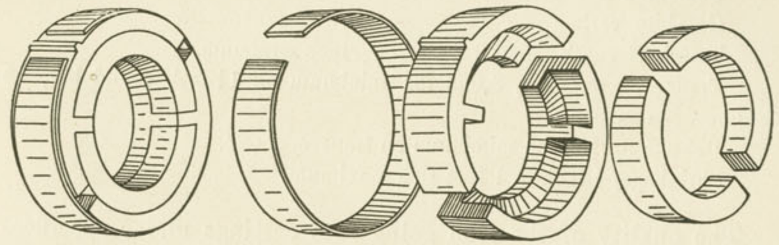


Fig. 12.

METALLIC PACKING RINGS.

This packing is contained in a metallic vibrating case, with discs forming its ends and fitting the rod packed. The case with the packing moves as a unit to accommodate any movement of the rod. The soft rings are thus protected from shocks or blows, as any sliding or rolling action is received upon the hard surfaces of the casing. The soft metal rings which do the packing only act when the throttle is open.

The arrangement of packing rings is shown in Fig. 12, each complete packing ring consisting of an outer and inner ring, each of which is in two or more pieces. The outer ring is L-shaped in form, while the inner ring is rectangular. The inner ring fits in a recess on the face of the outer ring, and is held in a fixed position by the lug in the recess of the outer ring. The pressure of the steam gradually stretches and closes the outer ring around the inner ring, thus automatically taking up the wear.

Specifications for Locomotive Cylinder Castings, Cylinder Bushings, Cylinder Heads, Steam Chests, Valve Bushings and Packing Rings. The following specifications for locomotive cylinder castings, cylinder bushings, cylinder heads, steam chests, valve bushings and packing rings are adopted as standard by the Master Mechanics' Association.

The material used in such castings must conform to the following specifications:

Silicon	1.25 to 1.60 per cent.
Phosphorus	.50 to .80 " "
Sulphur	.06 to .10 " "
Manganese	.30 to .60 " "
Combined carbon	.50 to .70 " "
Graphite carbon	2.75 to 3.25 " "

Tensile strength, 25,000 lbs. per sq. inch minimum.

Transverse strength, 3,000 lbs. minimum on 1¼-inch round bar, 12 inches between supports.

Deflection, .10 inch mimimum on transverse test.

Shrinkage, ⅛ inch in 1 foot as a maximum.

The quality of the iron going into castings under specification shall be determined by means of the " arbitration bar." This is a bar 1¼ inches in diameter and 15 inches long. It shall be prepared as stated further on and tested transversely. The tensile test is not recommended, but in case it is called for, it may be made from any of the broken pieces of the transverse test. The expense of the tensile test shall fall on the purchaser.

The tensile test piece should be prepared with threaded ends 1¼ inches in diameter, and with a central neck of 0.8 inch diameter, 1 inch between shoulders, with a 7-32 inch radius at the shoulders, the shoulders being 1 inch in diameter and ¼ inch in length to the thread, the total length of piece being about 3½ inches.

Two sets of two bars shall be cast from each heat, one set from the first and the other set from the last iron going into the castings. Where the head exceeds 20 tons, an additional set of two bars shall be cast for each 20 tons or fraction thereof above this amount. In case of a change of mixture during the heat, one set of two bars shall also be cast for every mixture other

than the regular one. Each set of bars is to go in a single mold. The bars shall not be rumbled or otherwise treated, being simply brushed off before testing.

The transverse test shall be made on all the bars cast with supports 12 inches apart, load applied at the middle, and deflection at rupture noted. One bar of every two of each set made must fulfil the requirements to permit acceptance of the castings represented.

The bars shall be molded two in a flask and cast on end; the bottom of the bar being $\frac{1}{16}$ inch smaller in diameter than the top, to allow for draft. Pattern shall not be rapped before withdrawing. The flask is to be rammed up with green molding

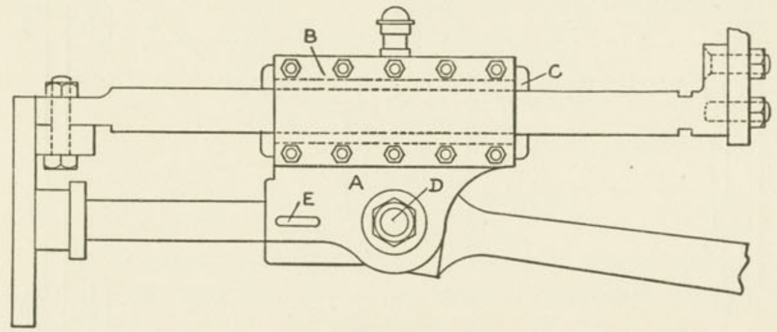


Fig. 13.

One Guide Crosshead.

sand, a little damper than usual, well mixed, and put through a No. 8 sieve with a mixture of 1 to 12 bituminous facing. The mold shall be rammed evenly and fairly hard, thoroughly dried, and not cast until it is cold. The test bar shall not be removed from the mold until cold enough to be handled.

The rate of application of the load shall be from 20 to 40 seconds for a deflection of 0.10 inch.

Borings from the broken pieces of the arbitration bar shall be used for the chemical determinations. One determination for each mold shall be required.

For cylinder heads, steam chests and packing rings the silicon must run between 1.60 and 1.80 per cent, the other elements remaining as above. If cylinder castings are to be bushed from the start, and also have valve bushings or false valve seats, they should be made of this latter grade of iron.

Cross-head and Cross-head Guides. The cross-head to which the piston rod is attached derives its name from the fact that, as ordinarily constructed, it forms a cross shape head on the rod. The cross-head and the cross-head guides, which control the motion of the piston rod, are complements of each other, and the form number and arrangement of the guides will depend on the kind of cross-head used. The function of the guides is to prevent the end of the piston rod from bending out of the axis of the cylinder,

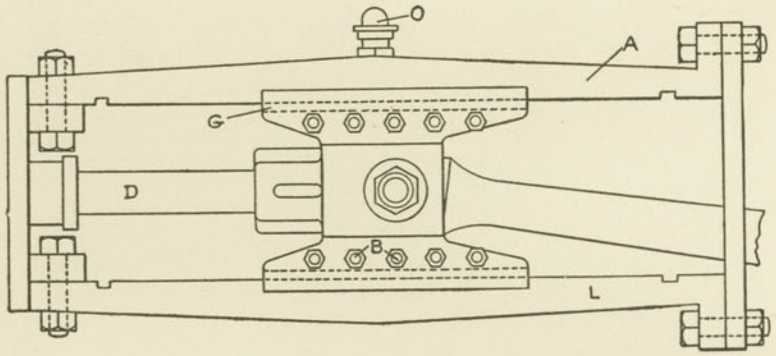


Fig. 14.

Two Guide Crosshead.

and they must, therefore, be parallel to it. The guides may number one, two or four, depending on the kind of cross-head used. A type of cross-head used on light engines, where one guide is used, is shown in Fig. 13. A form where two guides are used is shown in Fig. 14, and the most usual form, where four guide bars are used, is shown in Fig. 15.

As shown in Fig. 13, the cross-head for the single guide entirely envelops the guide, and consists of the following parts: A is the cross-head proper; B, cross-head block; C, cross-head gib; D, cross-head pin washer and nut, and E, the cross-head key. Fig. 14 represents a type of cross-head used quite often on freight engines; A is the upper guide bar; L, the lower guide bar; D

represents the piston rod; G, represents the cross-head gib; B represents the cross-head nuts, and O represents the cross-head oiler.

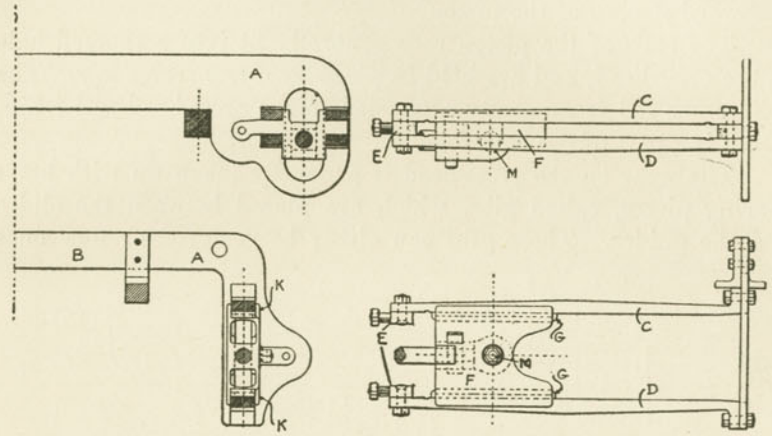


Fig. 15.

Four Bar Type Crosshead.

The four-bar type, which was at one time almost universally used, is shown in Fig. 15. A represents the guide bar; B, the guide-bearer knee; C, the top guide bar; D, bottom guide bar; E, guide blocks; F, cross-head; G, cross-head gibs, and M, cross-head pin.

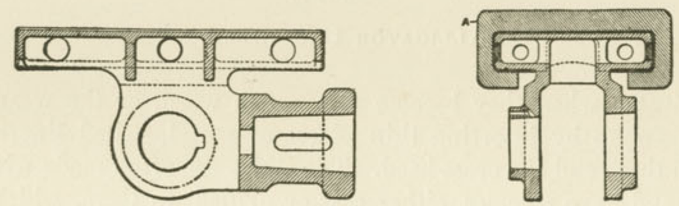


Fig. 16.

Crosshead with Large Bearing Surface.

Another form of cross-head is shown in Fig. 16. This is an improved form, in which exceedingly large bearing surfaces are obtained. These are also well protected from the dust. The guide is shaped as shown in the section at A. It will be seen that the bearing surface on the top of the cross-head is very large, because when an engine is running forward the angularity of the connecting rod tends to lift the cross-head on both the forward and backward strokes of the piston.

The ends of the piston rods generally fit into a tapered hole in the cross-head, and are held in place by a transverse key. The connecting rod is generally connected to the cross-head wrist pin, which is a part of the cross-head.

The wear on the cross-head is generally taken up with brass bearing pieces, called gibs, which are placed between the slides and the guides. These gibs can either be removed or new ones

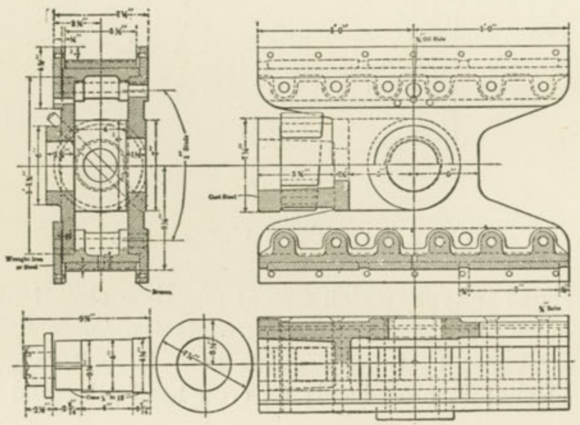


Fig. 17.

Alligator Crosshead.

substituted when they become very much worn, or the wear can be taken up by inserting thin pieces of metal, called liners, between them and the cross-head. The slides are often made without gibs, and have recesses, either cast or drilled, in them, which are filled with Babbitt metal. The slides are generally oiled by means of an oil cup attached to the top guide, and are so constructed that the oil will gradually be fed on the slides, which are thus constantly and regularly lubricated.

The alligator cross-head, shown in Fig. 17, has been used on the Canadian Pacific Railway with very satisfactory results. The most important advantage is that the bearing strips or gibs,

which may be made in one or more pieces, can be lined up, or removed and replaced, at a comparatively small expense, it being unnecessary to disconnect the cross-head from the piston rod. All that has to be done is to slack off the nuts on the through bolts and remove the side plates. The slippers are of cast steel, and divided by cross-webs, forming end checks for the gibs; the intermediate webs are removed when the gibs are made in one piece. The side plates, when bolted up, form a clamp to hold the gibs in place.

Cross-head Pin. The connecting rod requires a pin on which to oscillate while transmitting its motion to the crank. It is usual to make this pin fast in the cross-head and have the connecting

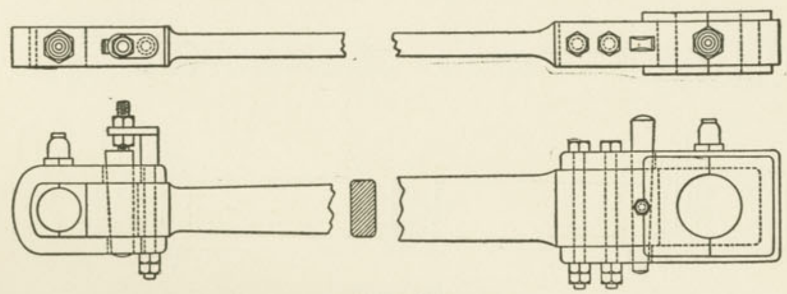


Fig. 18.

Connecting Rod.

rod swing on it. It is usual to make the wrist pin hollow, in order that the oil may be introduced through the center, and so that the oil can flow out by a radial hole through the contact surface.

Connecting Rod. The connecting rod must transmit the alternate pull and push of the steam to the revolving crank pin. It must be strong enough to withstand the tendency to bend transversely by revolving effect caused by its own weight, and it must be constructed so as to arrange for a bearing at each end. Since the entire pressure of the piston must be borne upon relatively small areas of the wrist and crank pin, there must be some arrangement for taking up the wear. The cross sections of the connecting rod, to meet these requirements, are either rectangular or I-shaped. The latter has become very much used on locomotives, as the two flanges give strength against deflection, and all unnecessary metal is removed.

The ends of the rod are equipped with stub ends or strap ends, similar to those shown in Figs. 18 and 19. The ends of these rods are provided with what are called brass bearings or brasses. These brasses are made in pairs, so as to embrace the pins from each side. They are held in place by straps, which are bolted to the connecting rods. When the brass bearings become worn they are taken out of the straps, and a portion of their surface of contact with each other is filed away, thus allowing them to come nearer together, and thereby reducing the size of the hole which receives the pin or journal.

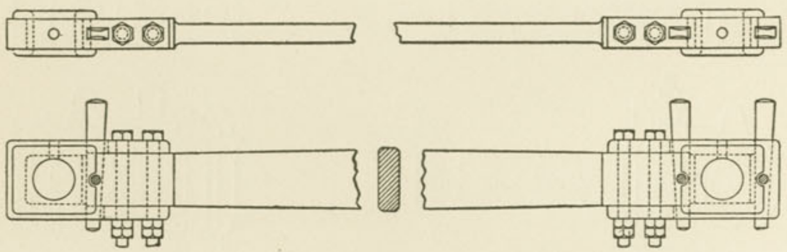


Fig. 19.

Connecting Rod.

Another plan is to have the joint open a little when the two half bearings are in place, and to fill the gap with liners of thin sheet metal, so that the bearing can be made solid. As the bearing surfaces wear, these liners are sucessively taken out until the joint comes together, when refitting is necessary. In order to prevent the brasses from being loose in the straps, tapered or wedge-shaped keys are fitted in the straps and rods. By driving down these keys the straps are drawn against the brass bearings, and they are forced together, thus reducing the size of the hole for the journal and making the rods fit tightly on the pin. A hard steel plate is sometimes interposed between the keys and the brasses to prevent the keys from indenting the surface of the soft brass.

In order to prevent the keys from working loose, they are held in place either by screws or nuts. The journals of the crank

pins are oiled by means of oil cups attached to the straps above the journals. Sometimes the oil cups are attached to the under side of the straps.

These are filled with oil, which is agitated violently by the rapid motion of the rods. The brasses are usually lined with Babbitt or some other kind of soft metal, so that there is less liability of the journals heating up.

The rods which connect or couple together the crank pins on adjoining driving wheels are called coupling rods, or parallel rods, and they are made very similar to the connecting rod, or to the form shown in Fig. 20. Parallel rods are also made with an I-section, for the same reason as in the case of connecting

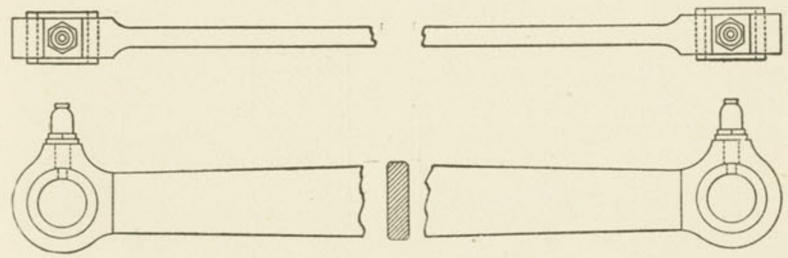


Fig. 20.

Parallel Rod.

rods. The side rods are generally fitted with brass bushings, which are pressed into position, and are sometimes held from turning by a set-screw. These brasses have no means of adjustment, and, when worn, they must be replaced by new ones, bored to fit the pin.

The stresses to which parallel and connecting rods are subjected are very severe. They are of a twofold character; one is due to the direct thrust of the piston, the other is the centrifugal force, due to the rotary motion of the parts. The latter has a greater influence upon the parallel or side rod than upon the connecting rod. The former has the greater influence upon the connecting rod. In an eight-wheeled locomotive, with four wheels coupled, the parallel rod is supposed to transmit one-half the thrust of the piston to the rear wheel.

The thrust of the piston upon the connecting rod may be expressed by the formula:

$$T = \frac{P\ A}{2}$$

in which

T = the thrust on the parallel rod.
P = steam pressure in pounds per square inch.
A = area of piston.

Crank Pins. Crank pins are made of wrought iron or steel, and are accurately turned to the size required for the journals of

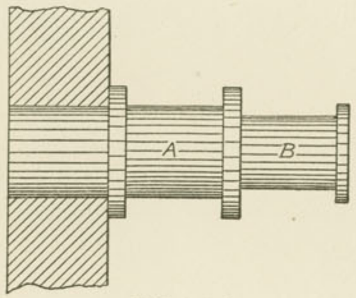


Fig. 21.

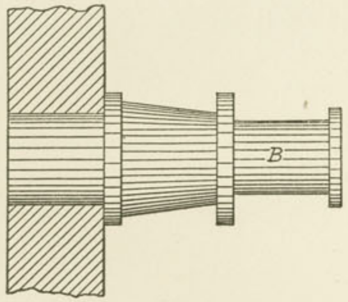


Fig. 22.

CRANK PINS.

the connecting rods, as shown in Fig. 21. The main crank pin has two journals, one A, to which the crank rod is attached, and the other B, to which the coupling rod is attached. The back pin, shown in Fig. 22, has only one journal, B, for the coupling rod. Sometimes the connecting rod is attached to the outside journal B, and the coupling rod to the inside journal. The crank pins are made with collars, which hold the rods on the pins. The crank pin and back pin are turned so as to fit accurately into holes which are bored in the wheels, and they are either driven in or pressed in with a screw or hydraulic press. Sometimes the holes are bored tapered, and are secured by a large nut and key on the inside of the wheel.

Adjusting Rod Brasses and Setting Up Wedges. When setting up the wedges, the engine should be placed with the crank pin of the right side on the upper forward eighth, which brings the crank pin of the left side on the back upper eighth. Block the wheels, and with the reverse lever in the forward motion apply a small quantity of steam. As the action of the steam against the piston has a tendency to move it forward, the strain is thrown against the shoes, permitting a free movement of the wedges. The wedges should be set up with an ordinary wrench as far as possible, and then pulled down again about one-eighth of an inch, to prevent the box from sticking, either from overheating of the box or defective lubrication of the wedge.

Rod brasses should be keyed by driving down just enough to bring together brass to brass. Any greater force would spring the crown of the brass against the pin and cause it to heat. If the main rod is to be keyed, place the side of the engine upon which the work is to be done either on the upper forward eighth, or the lower back eighth, as these positions present the greatest diameter of the pin to the rod brass, and guarantee a free movement at all points without binding.

Brasses should be keyed up properly to prevent unnecessary shocks and heating of rod brasses, and pounding in driving boxes, which in time cause undue strain on the entire motion with disastrous consequences.

The side rods on Mogul and Consolidation locomotives should be keyed by placing the engine on the dead center, either forward or back. First key the middle connection, next the ends of rods, and observe that the rods move freely on the pin. Now place the engine on the opposite dead center, and notice if the rods move freely at this point also. This is particularly necessary with rod brasses having keys on both sides of pin, and which are apt to be made either too long or too short, throwing the rods out of tram, and causing undue strain on rods and driving boxes, and also danger of broken rods or pins. By an engine out of tram is meant one whose distance from center to center of axle or rod on one side does not coincide with the similar distance on the opposite side; or it may mean that the distance between two connected crank pins is not the same as the distance between the two axles to which the crank pins belong.

LOCOMOTIVE RUNNING GEAR.

By the running gear of a locomotive is meant those parts of the engine, such as the wheels, axles and frames, which carry the other parts of the engine. The wheels are divided into two

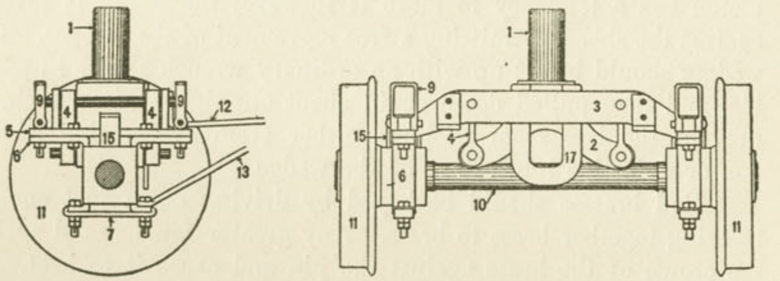


Fig. 23.

Baldwin Two-Wheel Engine Truck.

classes: driving wheels and truck wheels. The driving wheels move the locomotive on the track, and their adhesion depends on the pressure with which they bear on the rails. The driving wheels carry a large part of all the weight of the engine.

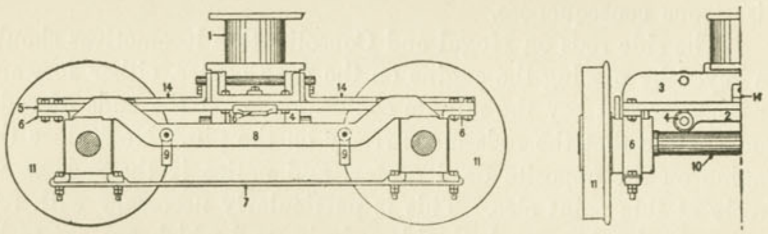


Fig. 24.

Baldwin Four-Wheel Engine Truck.

Locomotive Trucks. A locomotive truck consists of one or more pairs of wheels which are held in place by a separate frame, which is attached to the locomotive by means of a center pin or king bolt, so that it can turn to accommodate itself to meet the curves of the track. Figs. 23 and 24 show two types of engine

trucks in use upon Baldwin locomotives. 1 is the center pin; 2, swing bolster; 3, swing bolster crosstie; 4, swing bolster link; 5, truck frame; 6, truck pedestal; 7, truck pedestal cap; 8, equalizing beam; 9, spring link; 10, axle; 11, wheel; 12, radius bar; 13, radius bar brace; 14, longitudinal brace; 15, spring staple; 16, spring seat, and 17, safety strap. Two forms of engine trucks

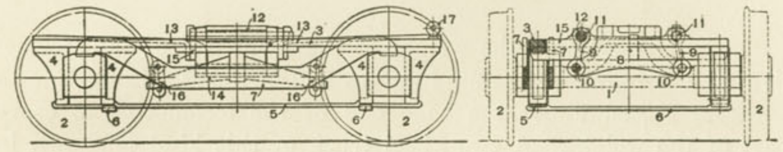


Fig. 25.

American Four-Wheel Engine Truck.

used upon light locomotives, built by the American Locomotive Company, are shown in Figs. 25 and 26. In Fig. 25 the engine truck axle is represented at 1; 2, engine truck wheel; 3, the engine truck frame; 4, engine truck pedestal; 5, engine truck pedestal cap; 6, engine truck equalizer; 8, engine truck swing bolster; 9, engine truck spring link; 10, 11, engine truck swing link pins; 12, engine truck swing link pin thimble; 13, engine truck frame

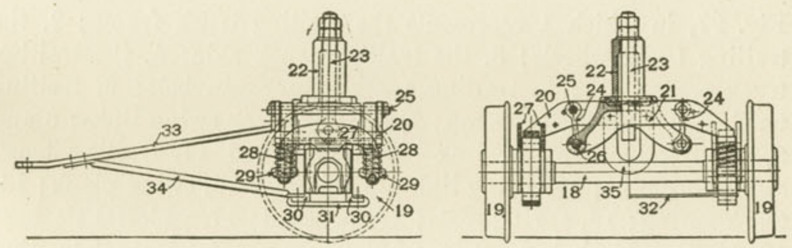


Fig. 26.

American Two-Wheel Engine Truck.

brace; 14, engine truck spring; 15, engine truck swing bolster frame; 16, engine truck spring hanger, and 17, engine truck safety chain bolt.

In Fig. 26, which represents a single pair of truck wheels, 18 represents the engine truck axle; 19, engine truck wheel; 20, engine truck swing bolster frame; 21, engine truck swing bolster; 22, engine truck center pin; 23, engine truck king bolt; 24, engine truck swing link; 25 and 26, engine truck swing link pins; 27, engine truck equalizer; 28, engine truck spring; 29, engine truck spring seat; 30, engine truck pedestal; 31, engine truck pedestal cap; 32, engine truck pedestal crosstie; 33, engine truck radius bar; 34, engine truck radius bar brace; 35, engine truck safety valve.

The trucks carry the weight of the front end of the locomotive, and also guide it around curves and switches. Sometimes a truck is placed under the back end of the locomotive to carry part of the weight. A two-wheel truck of this kind is shown in

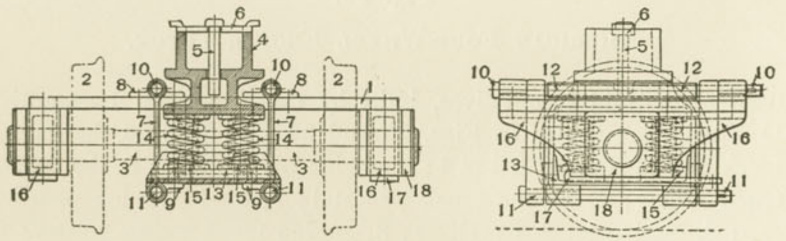
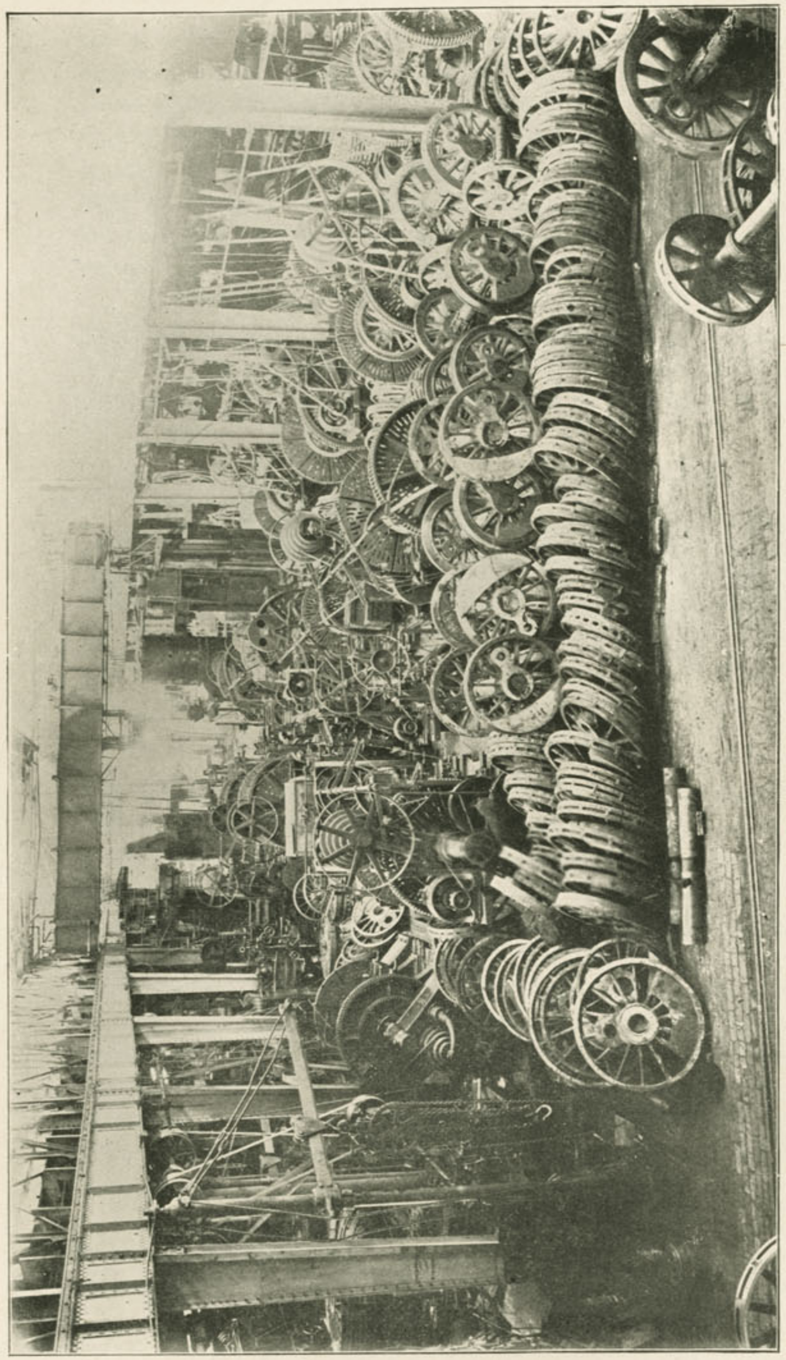


Fig. 27.

Two-Wheel Trailing Truck.

Fig. 27, in which 1 represents the trailing truck frame; 2, the trailing truck wheels; 3, the trailing truck axle; 4, the trailing truck center pin; 5, trailing truck center pin bolt; 6, trailing truck center pin safety strap; 7, trailing truck swing links; 8 and 9, trailing truck swing link bolster; 10 and 11, trailing truck swing link pins; 12, swing link pin thimble; 13, swing plank; 14, truck spring; 15, spring seats; 16, pedestal; 17, pedestal tie bar; 18, trailing truck box. Fig. 28 represents a four-wheel trailing truck, in which 19 represents the frame top bar; 20, frame arch bar; 21, frame tie bar; 22, wheels; 23, axles; 24, frame filling; 25, truck transoms; 26, swing links; 27, swing link bars; 28, swing link pin; 29, center plate; 30, truck spring, and 31, trailing truck box.

When two pairs of wheels are used, as shown in Fig. 25, both axles are attached to the same frame, which is connected to the engine by the center pin between the two axles by swinging



DRIVING WHEEL SHOP—BALDWIN LOCOMOTIVE WORKS

around the center of the pin. Trucks which have one pair of wheels sometimes have the center pin placed some distance behind the center of the axle, to facilitate the wheels moving around the curve.

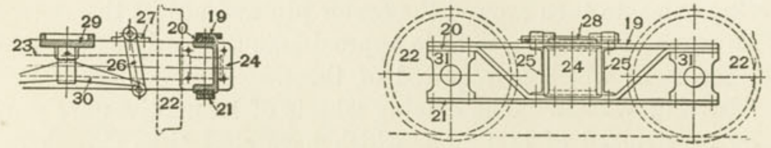


Fig. 28.

Four-Wheel Trailing Truck.

The periphery or tread of each wheel is made conical so as to facilitate their moving around curves, and the flanges are put

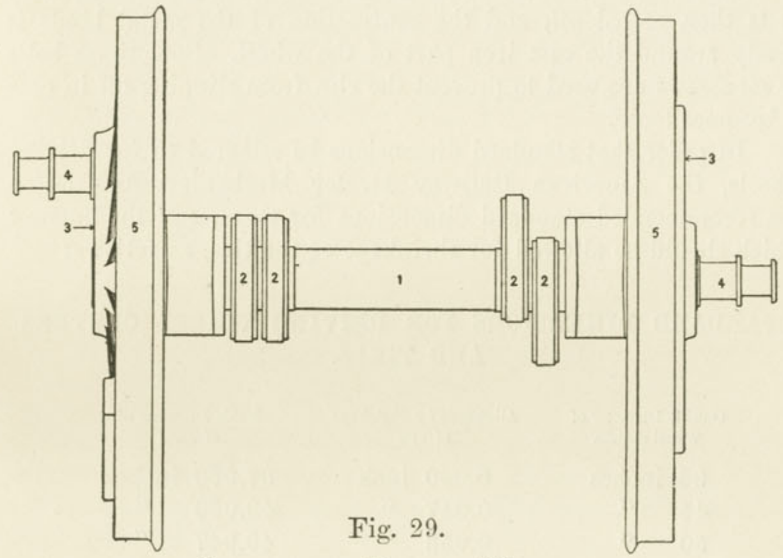


Fig. 29.

Locomotive Driving Wheels.

closer together than the rails, so that there will be more space or end play between the flanges and the rails. In running on a curved track the truck wheels will roll toward the outer rail of the curve, and the outside wheel will rest on the rail near the flange, where the diameter is larger, and the inside wheel will rest on the rail, where the diameter is smaller, and consequently the periphery of the two wheels will move with different velocities.

The truck is attached to the locomotive by the center pin, which allows the truck axles, instead of remaining parallel to the driving axles, to turn around the center pin and adjust themselves to the curve of the rails, so as to approximate as closely as possible the movement which is required of them.

Driving Wheels. The driving wheels of locomotives are generally constructed of cast iron, which have steel tires shrunk on the outside. The center portions of the wheel, that is, the hub, spokes and rim, are cast in one piece, as shown in Fig. 29; 1 is the driving axle; 2, the eccentrics; 3, the wheel center; 4, the crank pin, and 5, the tire. The insides of the tires are usually turned out somewhat smaller than the outside of the wheel center; the tire is then heated so that it will expand enough to go on the center. It is then cooled off, and the contraction of the metal binds it firmly around the cast iron part of the wheel. Sometimes bolts or set-screws are used to prevent the rim from slipping off in case it becomes loose.

In order that standard dimensions be adhered to for driving wheels, the American Railway Master Mechanics' Association has recommended standard dimensions for them, and the amount which should be allowed for shrinkage of the tire, as follows:

STANDARD DIMENSIONS FOR DRIVING WHEEL CENTERS AND TIRES.

Outside Diameter of Wheel-centres	Allowance for Shrinkage of Tire	Inside Diameter of of Tires
38 inches	0.040 inch	37.960 inches
44 "	0.047 "	43.953 "
50 "	0.053 "	49.947 "
56 "	0.060 "	55.940 "
62 "	0.066 "	61.934 "
66 "	0.070 "	65.930 "

The driving wheels are fastened to the axles by means of hydraulic pressure, the hubs are accurately bored out to receive the axles, and the axles are turned so as to fit the hole bored in

the wheel. The axles are then forced on to the wheel by powerful pressure. The axles are also keyed fast with square keys, driven into grooves cut in the axle and in the wheel, so as to prevent the wheels turning upon the axles.

The shape of the tread and flange of a locomotive wheel should be turned up to the standard which has been adopted by the Master Car Builders' and Master Mechanics' Association, the section of a standard tread and flange being shown in Fig. 30.

Counterbalance Weight. On all locomotive drivers there should be some form of counterbalance weight used to balance the weight of the crank pins, connecting rods and pistons. The

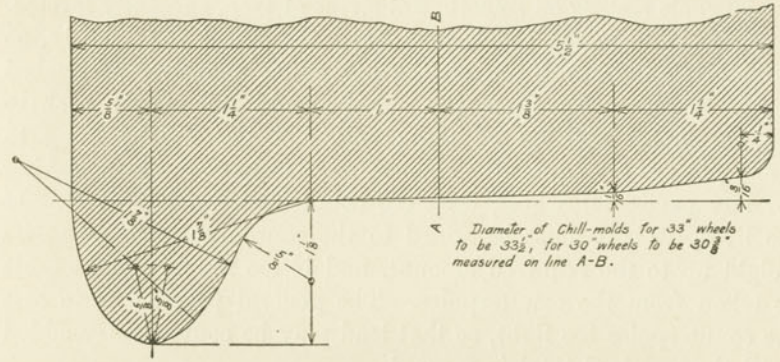


Fig. 30.

STANDARD TREAD AND FLANGE.

counterweight, in order to balance the reciprocating parts, must be heavier than the weight concentrated at the crank pin. The rule for finding the amount of counterweight required for a given engine is as follows:

To properly counterbalance a locomotive it is necessary to weigh the reciprocating parts, that is, the piston and rod, the cross-head and its pin, and the small-end half of the connecting rod (as explained subsequently) on one side, and add these weights together. Next couple all the parts of one side rod together, and having been carefully leveled, a series of knife edges should be passed through the crank pin holes, and all supported on suitable brackets or blocks. Then a weighing machine should be inserted under each knife edge in turn. In this way the proportion of side-rod weight borne by each wheel is ascertained. The big and little end halves of the connecting rod should then be weighed in the same way. The next operation is to write down the total weight for each wheel as follows: Two-thirds of the total weight of the reciprocating parts for each wheel, then the weights for each wheel ascertained by weighing the side rod. The main driving wheel has the big-end portion of the connecting rod added, and when this is done we have the amount to be balanced on each wheel at the radius of the crank pin. The counterweight of each pair of drivers must then be found by placing each pair on trestles, with the journals resting on smooth, flat strips of iron, carefully leveled. Hang weights to the crank pins until the wheel rolls slowly, so as to bring the crank pin on the horizontal quarter. If pushed gently in either direction, the wheel should roll slowly back to the horizontal position of the crank. If the weight hung to crank pin exactly equals the amount previously found by weighing for any particular wheel, then the counterbalance is correct. If too little, weight must be added to the counterpoise to bring its weight up to the required amount, and if too much, weight must be taken from the counterpoise. The general practice is to cast the counterpoise too light, so that lead may be conveniently added until the required total is secured.

Another method is as follows: Find the separate revolving weight in pounds of the crank pin, crank pin bars, coupling bars, and back end of connecting rod for each wheel; also reciprocating weight of the piston, piston rod, cross-head and front end of the connecting rod. Take about one-half of the reciprocating weight and divide it equally between the wheels, and add this amount to the revolving weight on each wheel. This sum is the weight to be balanced at each wheel, therefore, multiply this weight by the length of the crank in inches, and divide by the distance in inches of the center of gravity of the space to be occupied by the counterweight, the result will the weight required in pounds, which must be placed directly opposite to the crank pin. If the reciprocating parts are not balanced properly it will result in what is known as a hammer plate on the rails, and will not allow an even turning movement of the wheel.

Truck Wheels. Truck wheels are usually made of cast iron in one piece, and are often made smooth on the outside, with ribs on the inside, the plates which form the center of the wheel being curved. They are made in this shape, so that when the wheel is cast and contracts in cooling there is no danger of having the wheels become cracked. The tread of the wheel is hardened by a process called chilling; this is done by pouring the metal against iron into a mold of the form of the tread of the wheel. The mold of the tread is also made of cast iron, but, being cold, cools the moulten iron very suddenly, and thus hardens it so as to resist the wear upon it.

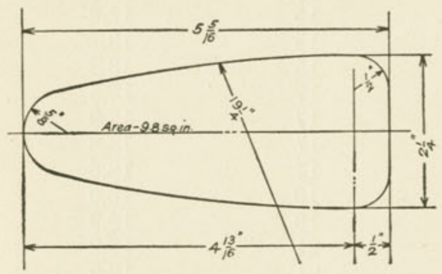


Fig. 31.

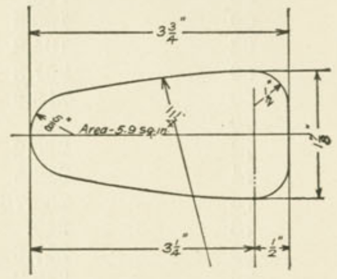


Fig. 32.

STANDARD SPOKE SECTIONS.

Shrinkage Allowed for Tires. The shrinkage allowance of tires adopted by the Master Mechanics' Association is as follows:

For cast iron and cast steel centers less than 66 inches in diameter, 1-80 inch per foot in diameter.

For cast iron and cast steel centers 66 inches and over in diameter, 1-60 inch per foot in diameter.

Spokes. In order to properly support the rim and resist the tire shrinkage, spokes should be placed from 12 to 13 inches apart from center to center, measured on the outer circumference of the wheel center.

The following rule is recommended by the Master Mechanics' Association:

Number of spokes to equal the diameter of center divided by 4. If the remainder is one-half or over, use one additional spoke. The exact spacing of the spokes, according to this rule, would be 3.1416×4.1256.

There is a feeling among pattern makers and foundrymen that an uneven number of spokes should be used to avoid getting two spokes directly opposite each other in a straight line. The following table has been made up on this basis:

Diameter	Circumference	Recommended Spokes	Pitch
38	119.38	11	10.8
44	138.23	11	12.5
48	150.8	11	13.6
50	157.	13	12.6
54	169.65	13	13.
56	176.	13	13.5
60	188.5	15	12.6
62	194,8	15	13.
66	207.3	15	13.8
68	213.6	17	12.5
70	220.	17	12.9
72	226.2	17	13.3
74	232.5	17	13.6
76	238.76	19	12.6
78	245.	19	12.9
82	257.6	21	12.2
86	270.2	21	12.9
90	282.2	23	12.2

Spokes at crank hub should not be located at center line of wheel, but on either side, so as not to bring a short spoke directly in line with crank-pin hub. Section of spokes at large end to have an area of from 9 to 10 inches, with form as shown in Fig. 31. Section of spoke at small end to have an area of from 5¾ to 6 inches, with form as shown in Fig. 32. These sections, as shown in Figs. 31 and 32, are taken at the base of the fillets uniting the spokes to the hub and rim.

Driving Wheel Centers. Cast steel driving wheel centers should preferably be uncut and shrinkage slots omitted; if cut, slots should be machined out and closed with solid cast iron liners driven in; no lead or white metal should be used.

For wheel centers, 60 inches or over, when the permissible total weight of the locomotive will allow, the rims should preferably be cast solid without cores, so as to obtain the maximum section and have full bearing on the tires. The section in square

inches should be approximately .45 of the sectional area of the tire when new.

The section of rim for wheel centers without retaining rings shall be of the form shown in Fig. 33.

The diameter of standard size center has varied from time to time, as the various designs of locomotives have sprung into

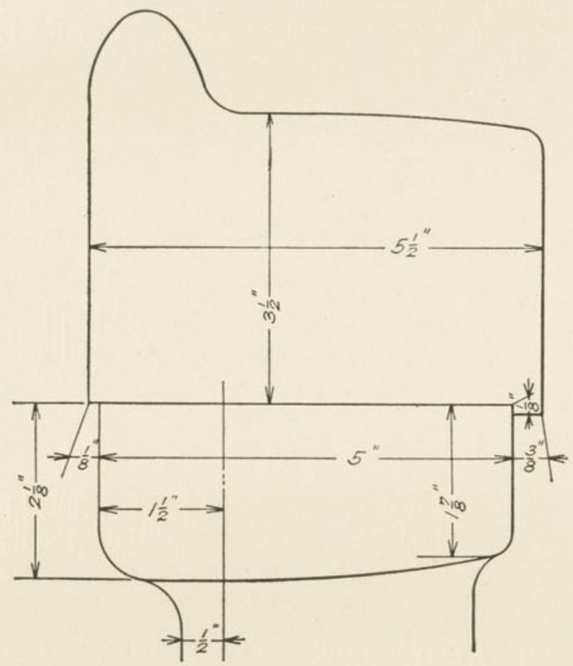


Fig. 33.

Standard Rim Section.

use, but in 1907 the Master Mechanics' Association adopted 72 inches as the standard size for large driving wheels.

A minimum thickness of one inch for the flanges of engine and truck wheels is also adopted as the standard practice.

The standard distance between hubs shall be 55 inches. This permits the use of a practically straight spoke without dish on the inside.

Frames. The frames of a locomotive are used for connecting the boiler to the running gear. They are fastened to the cylinder with wedges and bolts, and as the cylinders are bolted to the front end of the boiler the frames are rigidly attached to that end. The back ends of the frames are fastened to the fire-box with clamps, called expansion clamps. These clamps are so arranged that when the boiler is heated and expands the boiler can move in a longitudinal direction along the frame. They are made in various forms, depending upon the size of the locomotive

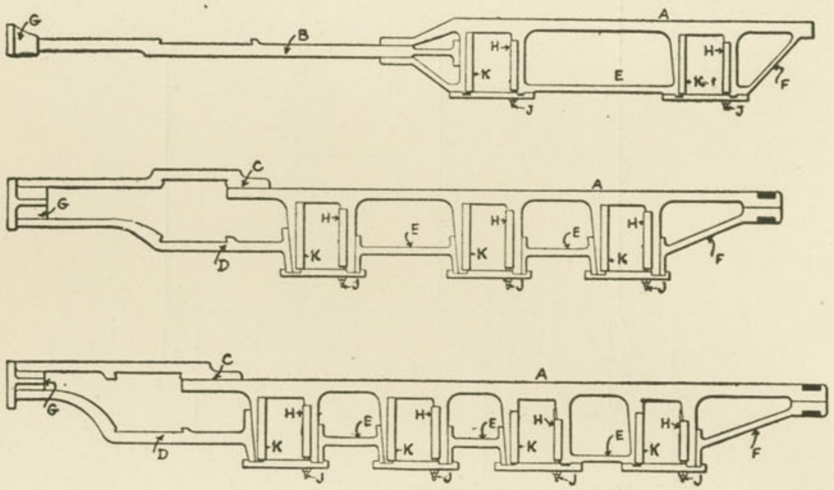
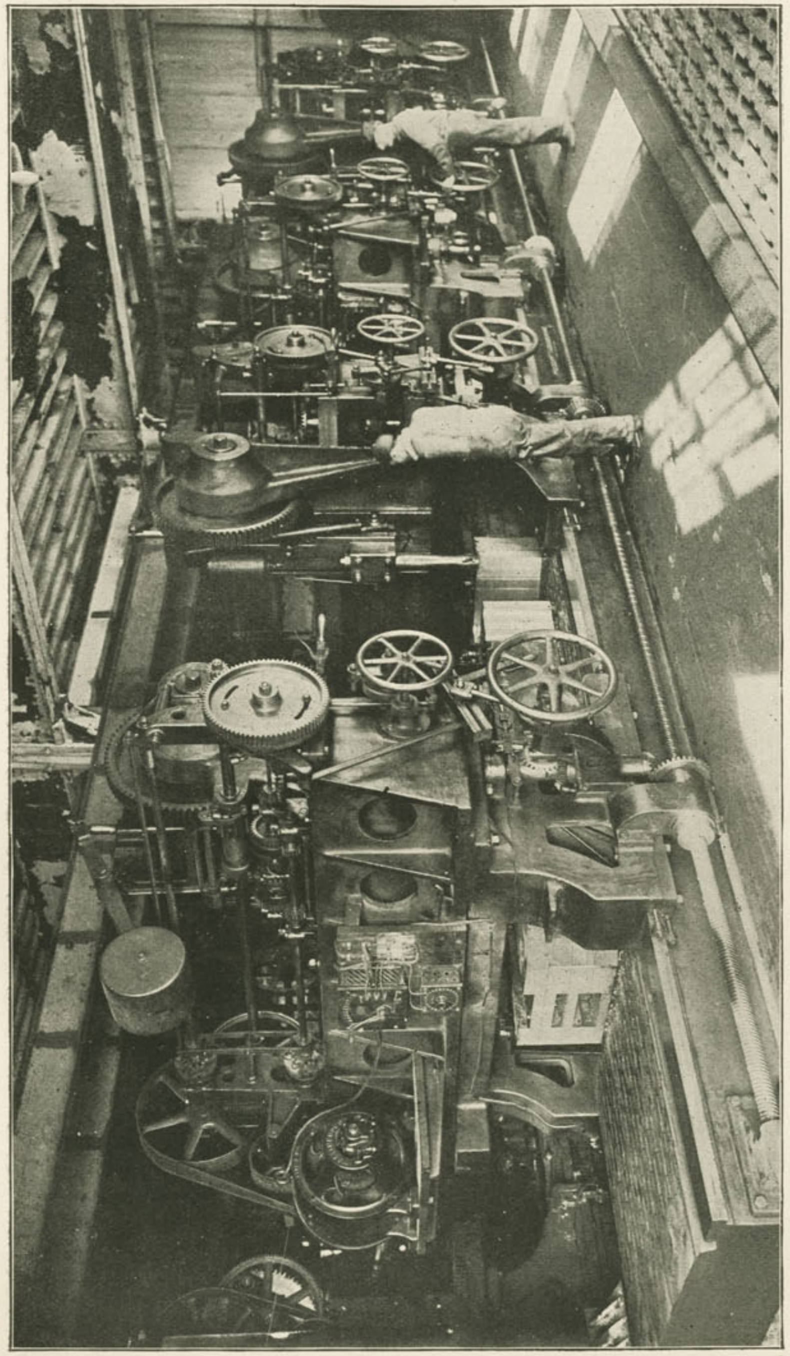


Fig. 34.

DIFFERENT TYPES OF FRAMES.

and the wheel arrangement. Several types of frames in use are shown in Fig 34, where A represents the top rail and pedestals; B, front rail; C, front rail top; D, front rail bottom; E, middle brace; F, back brace; G, frame filling piece; H, pedestal wedge; J, pedestal wedge bolt; K, pedestal gib.

The frames are not connected rigidly to the driving axle-boxes, but they are connected to them by means of springs. The frame is connected to the ends of the springs by means of rods or bars, called spring hangers. The driving axle-boxes are connected to the middle of the spring, so that the irregularity of the



QUADRUPLE-HEADED SLOTTING MACHINE. FRAME SHOP

(Baldwin Locomotive Works)

track and the hammer blow of the wheels are not felt to such an extent as if the frames were rigidly connected to the wheels.

Since the axle-boxes slide up and down in the jaws of the frame, the frames are protected from wear by means of shoes or wedges which bear against the frame. Only one of the shoes is made wedge-shape, and the wear is taken up by moving the pedestal wedge H by means of the pedestal wedge bolt J.

In the earlier forms of engines the frames were made of wrought iron, but large locomotive frames are now being made

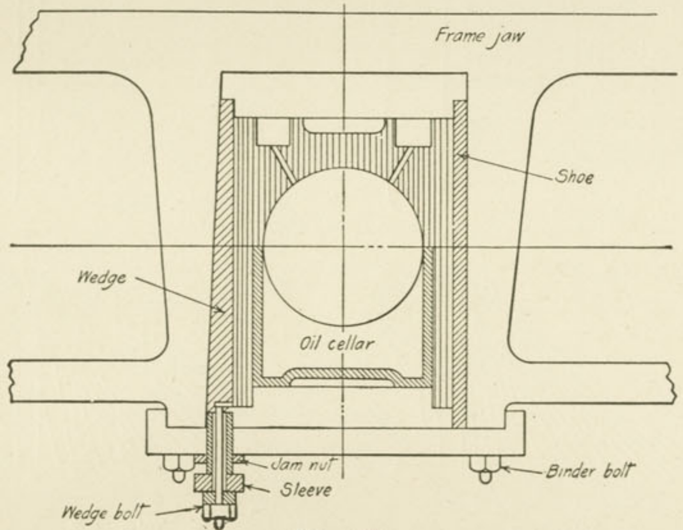


Fig. 35.

Pedestal Jaw and Driving Box.

of cast steel, which has proved so satisfactory that they are being extensively used on all types of engines.

Springs. The driving springs are placed over each driving-box, and are carried on a saddle which straddles the frame. They are either overhung or underhung, depending upon the design. In order to equalize the weight between the drivers equalizing bars are provided. These bars are attached to the frame with the springs between driving-boxes, the weight being suspended at the center of the bar or the axis of rotation. A bar of this kind equalizes the weight between the drivers, because if one driver goes up or down the end of the equalizing bar will go up or down with the box, and the weight will continue to be divided between the two boxes. The springs sit upon the spring saddle, which is a U-shaped iron spanning the frame, and a spring hanger is used for connecting the spring and equalizing bar.

Driving-boxes. Driving-boxes are set in the frames or pedestal jaws, and between them and the jaws are two pieces of

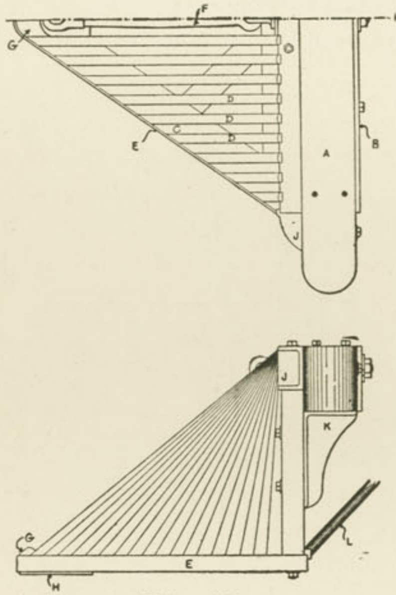


Fig. 36.

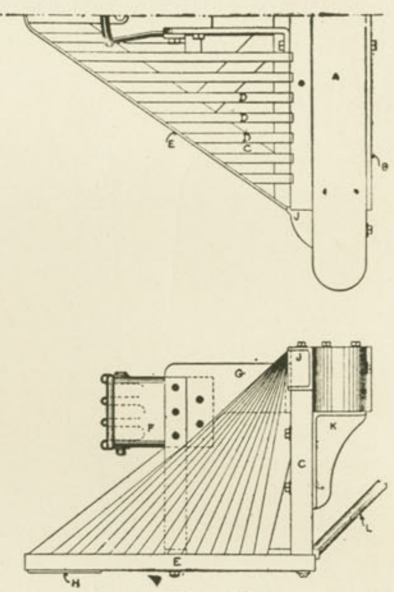


Fig. 37.

Pilots with Iron Draw Bar and Bull-Nose Attachments.

metal front and back, as shown at K and H, Fig. 34. The one in the front, H, is perfectly straight, and is called the pedestal wedge or shoe, and the one on the back, K, is called the wedge or pedestal gib, and is tapered. The jaw is also tapered so that any wear may be taken up, and also to allow the frame to move up and down. An arrangement of this kind is shown in Fig. 35.

Pilot. The pilot is placed in the front of a locomotive for the purpose of removing any obstacles on the track that would interfere with the operation of the locomotive. It may be made of either wood or iron, and consists of a triangular frame

at the bottom, which is supported so that it will be a few inches above the rails. Straight pieces of material are fastened to this frame at the bottom and to the bumper at the top, a few inches apart, which give to the pilot a peculiar form, which is well

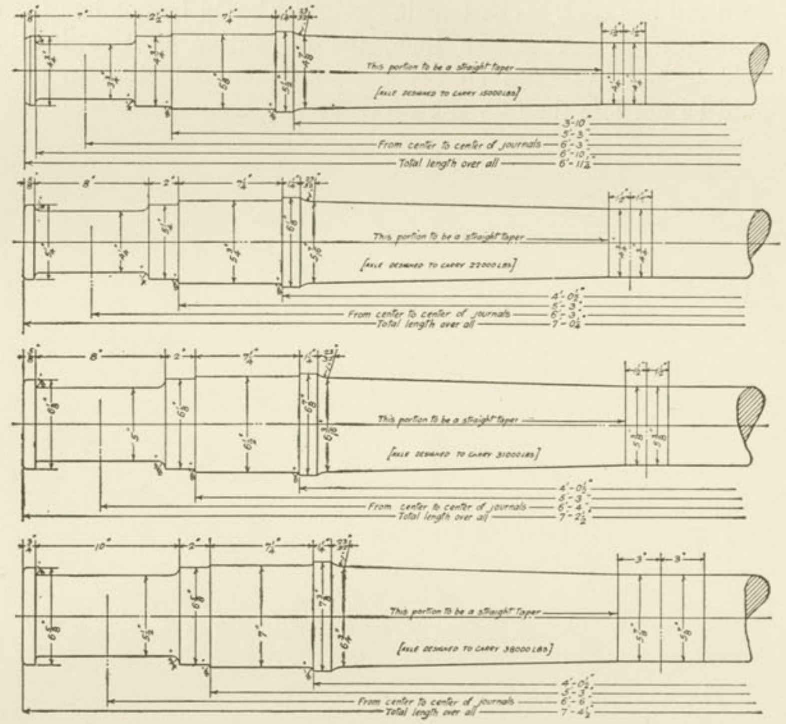


Fig. 38.

Standard Axles Adopted by the Master Mechanics' Association.

adapted for throwing obstacles off the track. Two forms of pilots are shown in Figs. 36 and 37. Fig. 36 represents a pilot with an iron draw bar attachment, and Fig. 37 a pilot with a bull-nose attachment, in which A represents the bumper; B, the stiffening plate; C, pilot frame; D, pilot bars; E, bottom band; F, draw bar or casting; G, pilot draw support; H, bottom plate; J, pushing shoe; K, pilot bracket; L, middle brace.

Engine Truck Axles. The four different standard axles adopted by the Master Car Builders from time to time are shown in Fig. 38. They must be made of open-hearth steel of the following chemical requirements: Phosphorus, not to exceed .05 per cent; sulphur, not to exceed .05 per cent; manganese, not to exceed .60 per cent. The tensile strength should be not less than 80,000 pounds per square inch, the elongation in two inches should be not less than 20 per cent, and the reduction in area should be not less than 25 per cent.

REVIEW QUESTIONS.

ENGINE PARTS AND RUNNING GEAR.

1. Explain the action of the steam in the cylinder of a locomotive.

2. How are the crank pins connected in relation with each other?

3. Why does not a locomotive stop on both dead centers at the same time?

4. Sketch a simple locomotive cylinder, and name the different parts.

5. What determines the size of cylinder of a locomotive?

6. Suppose the weight on the driving wheels is 105,000 pounds, the diameter of the driving wheels is 72 inches, the boiler pressure 200 pounds, and the piston stroke 24 inches, what should be the diameter of the cylinder?

7. Of what use is the counterbore, and why do cylinders always have them?

8. Of what use are cylinder cocks?

9. Of what use are pressure valves, and why are vacuum valves used?

10. Name three different types of pistons which may be used on a locomotive.

11. Why are piston packings used?

12. Explain the functions of a snap ring, and tell the method of making them.

13. How much larger is it usual to make a snap ring to fit a certain size cylinder?

14. What are the advantages of a follower piston over a box piston?

15. Explain several methods of fastening a piston rod to the piston.

16. Sketch a general form of stuffing-box, and explain how it takes up the wear on the piston rod.

17. How much phosphorus should be contained in a cylinder casting?

18. Explain how castings used in cylinders are tested.

19. Name three different types of cross-heads in general use.

20. How is the wear on the cross-head generally taken up?

21. How are the ends of the piston rods generally fitted into the cross-head?

22. What are the advantages of the alligator type of cross-head used on the Canadian Pacific Railroad, and how is the wear taken up with this type?

23. Why is a connecting rod of a locomotive generally of I-shaped section?

24. What are parallel rods, and why are they used?

25. Explain the method of taking up the wear in a connecting rod.

26. Explain the method of adjusting rods and brasses on a locomotive.

27. How are the side rods on Mogul and Consolidation locomotives keyed?

28. Name several different kinds of locomotive trucks.

29. Why is the tread of the wheel made conical?

30. How are the driving wheels of a locomotive generally fastened to the axle?

31. Of what use are counterbalanced weights on locomotives, and how are they calculated?

32. What is the shrinkage allowance of tires for locomotive driving wheels?

33. Explain why an uneven number of spokes is better than an even number of spokes in a driving wheel.

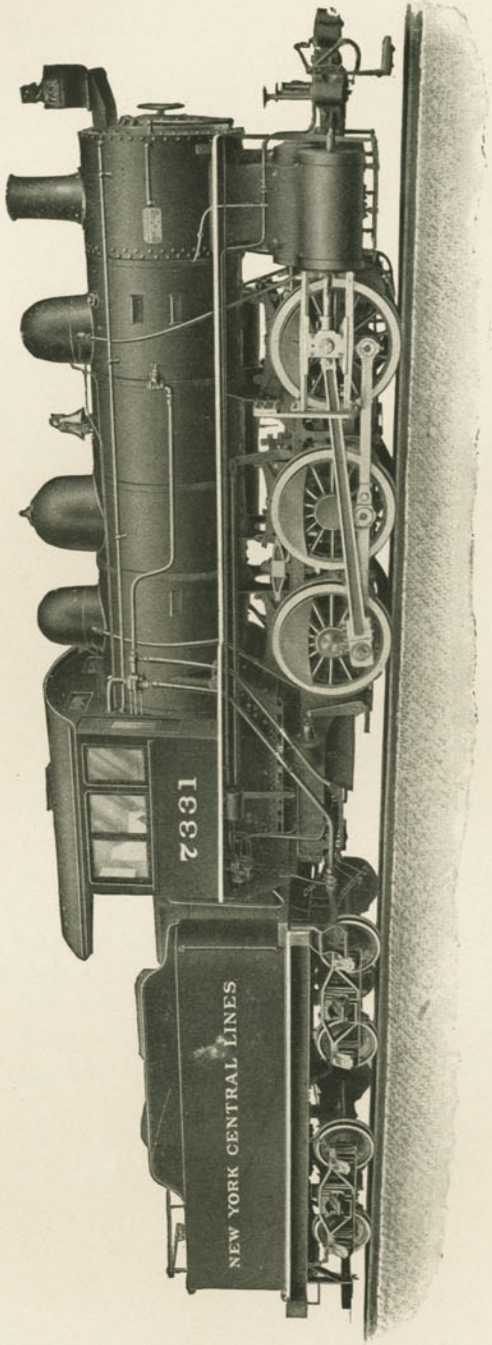
34. How are the frames connected to the engine?

35. Name two different kinds of pilots in general use.

36. Explain the method of taking up the wear in a driving-box.

37. Of what kind of material are axles generally made?

38. What is the standard distance between hubs of the driving wheels?



SIX WHEEL TYPE SWITCHING LOCOMOTIVE
(American Locomotive Company)

Locomotive Accessories

Along with the other improvements of the locomotive have come various improvements in the locomotive accessories. A considerable number of these improvements have been described in the various chapters on Mechanical Stokers, Boiler Fittings and Appliances, Engine Parts and Running Gears, etc., but there still remain some devices which belong neither directly to the boiler nor the engine, but which require special mention. Among these may be mentioned track-sanding apparatus, bell ringers, headlights, etc. Each of these accessories has been improved from time to time to meet the requirements of high speeds, long runs and quick stops, and for the purpose of lessening the labor of the fireman and engineer.

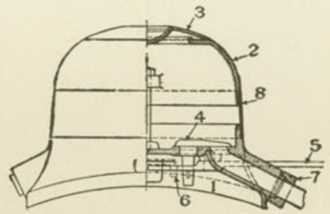


Fig. 1.

Sand Box.

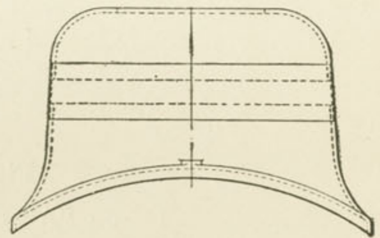


Fig. 2.

Dome Casing.

TRACK-SANDING APPARATUS.

The sanding apparatus on a locomotive has become an important feature on the present locomotive, and the principle and mechanism of a track-sanding apparatus should be as thoroughly understood as other parts of the locomotive. The sand box and dome casing are mounted on the top of the boiler, the details of which are shown herewith. Fig. 1 shows the usual form of sand box and Fig. 2 the dome casing. In Fig. 1, the sand box base is shown at 1, the sand box top at 2, the sand box cover at 3 the sand box valve at 4, the sand box lever at 5, the sand box connecting rod at 6, sand box pipe flange at 7 and the sand box connection sheet at 8. This arrangement shows the usual means employed to sand the rails, using the sand lever and valves over each sand pipe opening in the sand box.

In the more modern sanding apparatus, sand is made to flow by compressed air which economizes the amount of sand used and

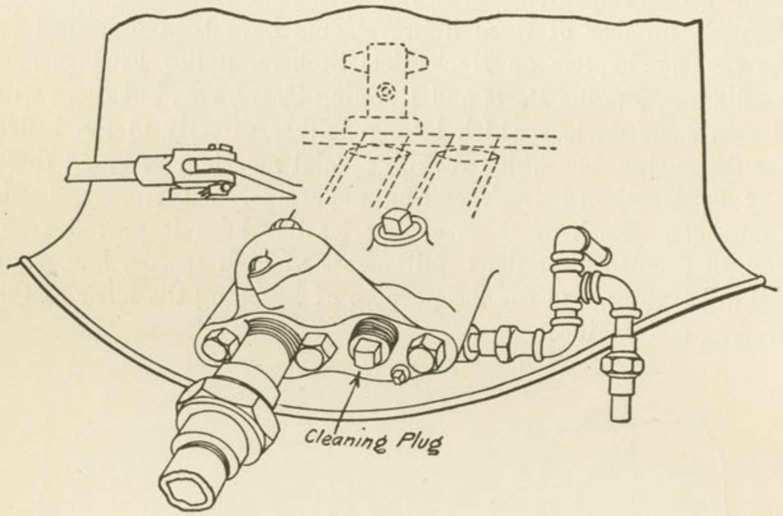


Fig. 3.

LEACH "A" SINGLE SANDER.

insures delivery at the proper time. The sanding is done automatically without special attention from the engineer. The application of the brakes will sand the tracks, or if so desired, the sanding apparatus can be made to act only on the emergency application. With the ordinary sanding apparatus, the engineer has to pull open the lever and sand the track. Of the different types of locomotive sanders in use, the Leach "A" sander, shown in Fig. 3, has been used widely, because of its simplicity of construction and the small amount of piping and connections to be kept tight.

The sander as shown, is used in combination with the gravity system of hand lever. The sand trap is divided into two compartments, with an opening between the two over the partition separating them. The sand traps are attached to the sand box in the most convenient manner, the sand being supplied through independent outlets from the box. The sand is discharged through the usual hand lever controlled pipes to the rail, the lever attachments being available for use as desired. There are two pipes between the trap and sand box, the discharge pipe to track being

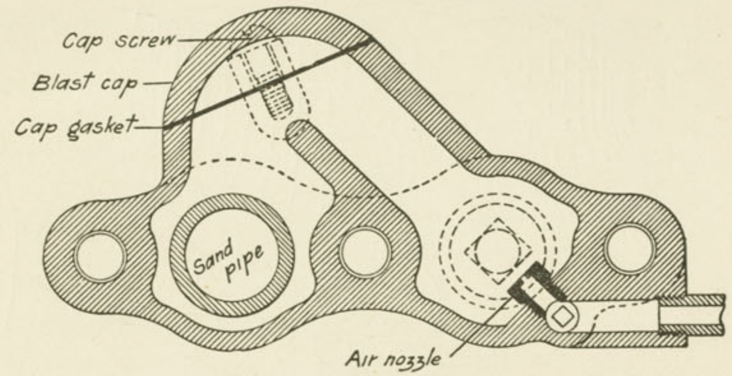


Fig. 4.

SINGLE SANDER TRAP.

attached to left side of trap, the air pipe being attached to the right side. The details of a single sander trap of this type is shown in Fig. 4. An air nozzle is screwed into the port at a proper angle, and above this nozzle is placed a hardened steel cap which is screwed into the trap for the purpose of withstanding the wear of the sand. Cleaning plugs are provided for cleaning out the trap.

When it is desired to use the hand lever, the sand will flow by gravity direct from the sand box to left side of trap into the sand discharge pipe. When using the pneumatic sander, the air issuing from the nozzle in the trap will blow sand over the top of the partition into the left side and out of the discharge pipe to rail, the right side of trap being kept full of sand by the pipe leading into that side, from sand-box. This type of sander is also made in the double pattern for supplying two lines of pipe.

Another style of sander in general use is known as the Leach "E" sander, shown in Fig. 5. Its advantages are that it is outside of the sand box; it is accessible at all times for inspection or when making repairs; and its operation can easily be seen. The resistance of the column of sand, always above the trap, prevents air pressure from escaping up through the sand box, and therefore a high pressure is available through discharge pipes for removing

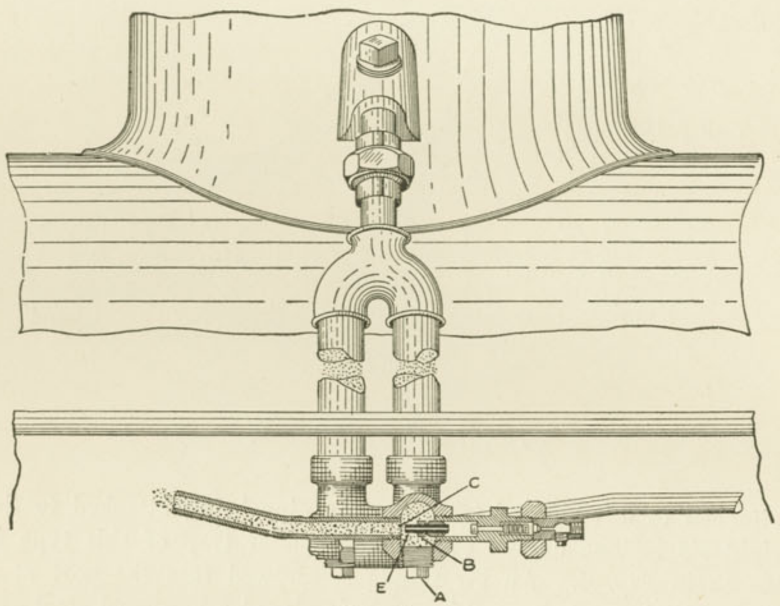


Fig. 5.

LEACH "E" SANDER.

obstructions in their lower ends. This is its fundamental and most essential feature. The air nozzle can be so adjusted as to regulate the amount of sand discharged to the rail. The nozzle is fitted with a small check valve, preventing the air passages from becoming plugged with sand. The discharge pipes are bent up 15 degrees, to prevent sand from jarring out of the traps when

the engine is running. A plug is arranged at the bottom of the trap so that any small stones, which may get into the trap, can be removed. This is shown at A, Fig. 5. The amount of sand delivered to the track is regulated by increasing or decreasing the distance C. This is done by loosening jam nut B, and moving the adjusting tube E, in or out. The greater the clearance C, the greater the sand delivery. Care should be taken to have the nozzles on opposite sides of the engine adjusted alike. When more than one delivery pipe is connected to the same trap, some provision must be made to prevent sand and air from going through the shorter delivery pipe. To meet this condition, the trap is arranged with separate compartments for each delivery.

As the greatest trouble with sanding devices has been the clogging up of the sand pipes, due to moisture entering the lower end of the sand pipe, a device known as the "She" sander, shown in Fig. 6, has been adopted to obviate this difficulty. This device consists of a siphon ejector placed within the sand box. It carries the sand to the rail with great velocity and uses a small amount of air to operate it. The air nozzles are always out of the sand, the siphon being in the center of the sand box where the sand is the driest.

The siphon consists of a single casting, having a pipe connection at each end, and bell-mouthed openings each side of center line with deflecting wings in front of openings. Above the center line of openings are ports which connect to the air pipes. These ports form the air nozzles, one each way. The discharge pipes at each end of the siphon lead down to track. The air pipes are connected, as in the other form of sanders, in the cab. When the air valve in the cab is opened, the air issues from the nozzles into the bell-mouthed openings, drawing the sand along with it, and forcing it out the discharge pipe onto the rail. When the emergency application of the brakes is used, the automatic port in the brake valve is brought into service, and the air escapes through that port into the pipe leading to the sanding device.

Another form of track sander in use is known as the Nathan steam sanding apparatus, shown in Fig. 7. The operation of this apparatus is effected by means of an ejector which supplies a combined jet of steam and sand to the point of contact between the driving wheels and the rails. The apparatus for a single sander, consists of one steam valve, one drip cock, two traps and two ejectors. When a double sander is used, the equipment consists of one double steam valve, two drip cocks, four traps and four ejectors.

The necessary requirements of operation of the Nathan steam sander are, that the sand must be absolutely dry and finely sifted; the cover of the sand-box must be water-tight, to prevent the sand from getting wet.

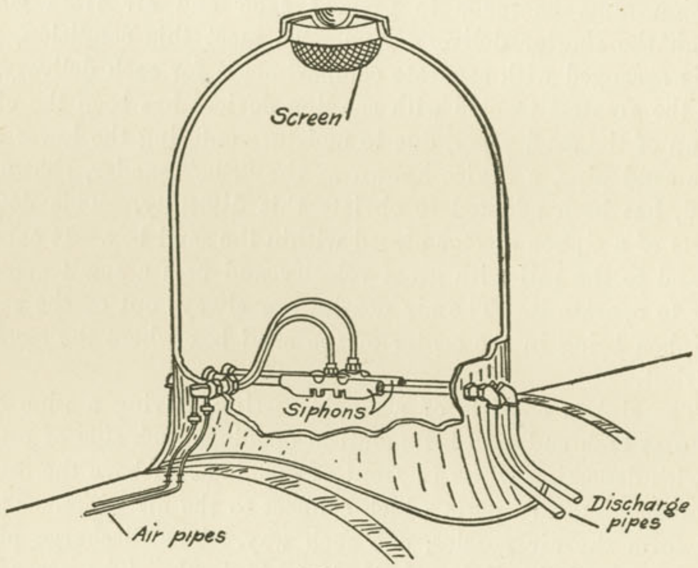


Fig. 6.

THE "SHE" DOUBLE SANDER.

The Nathan apparatus, as shown in Fig. 7, is applied to the engine as follows: The sand-trap is attached to sand-box or sand-pipes by means of the union couplings in the most convenient position; the plug must point straight downward, and the air snout must point in the direction of the delivery. The ejectoı is connected to sand-pipe in such a way, that the blast will strike in about the center betwen tire and rail. The steam valve is attached to dome, bridge-pipe, or other high place on boiler.

The automatic drip cock is connected to steam-pipe, and the steam-pipe is made to incline towards the drip cock in both directions, as shown in Fig. 7. This will lead the condensed water, resulting from a leakage of the steam valve, down the drip-pipe, and thus prevent the freezing of the ejector pipe in cold weather. The steam pipe is branched off to the ejector on each side of engine at a point between ejector and drip cock. The standard connections are made for 1-in. iron pipe for the sand traps. The steam pipe should be $\frac{3}{4}$-in., and connections on

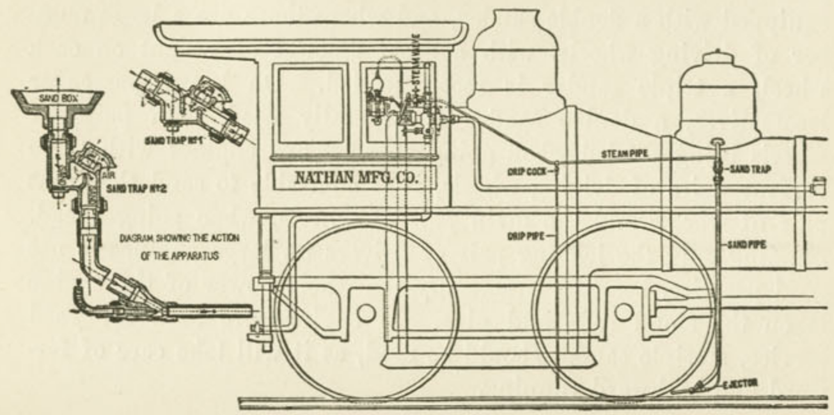


Fig. 7.

NATHAN STEAM SANDING APPARATUS.

ejector and drip cock will be furnished blank or cut for $\frac{3}{8}$-in. iron, or drilled for $\frac{1}{2}$-in. copper, according to orders. The bottom of the drip cock is tapped for $\frac{1}{4}$-in. drip pipe.

The method of operating consists of merely opening and closing the steam valve.

The advantages claimed for this apparatus are as follows:

1. The certainty of delivering sand at the proper point between the wheels and rails.

2. Saving in sand by being able to regulate the quantity delivered according to existing necessities.

3. Dispensing with rods and levers for working sand gear.

4. Capability of being applied to present sand-boxes without any alteration.

5. Simultaneous delivery of sand at the point of contact for both wheels, whereby the liability to injure the crank, driving axles, and coupling rods is greatly reduced.

6. Additional train resistance avoided, as no superflous sand is left on the rails as by the old method.

7. Economy of steam; there being no slipping or unnecessary revolving of locomotive wheels in starting engine.

Double and Triple Sanders. Heavy locomotives should be equipped with a double sander, and where there are a large number of driving wheels, with a great amount of weight on each wheel, a triple sander is recommended. On heavy passenger locomotives, a double sander is generally used, both pairs of wheels being sanded when going ahead. For engines with three or four pairs of driving wheels, it is advisable to sand the front pair of wheels and the main pair of wheels, when going ahead. Sanding only the leading pair of drivers on large engines is not good practice, because, practically the whole power of the engine is on the small rods and pins. If engines are used for yard service, a triple sander should be used, as it will take care of forward and backward running.

BELL RINGERS.

The bell on a locomotive is used for the purpose of giving notice of the starting or approach of a locomotive. It is always located at the top of the boiler, and is usually hung on a cast-iron frame and run with a rope, as shown in Fig. 8, in which A is the bell; B, the frame; C, the yoke; D, the crank; E, the tongue; and G, the acorn.

The duties of the firemen have increased so much with the increased size and speed of locomotives that it has become necessary on large locomotives to use some form of automatic bell ringer which will relieve the fireman from ringing the bell, so that he can devote his whole time to other duties.

An automatic bell ringer is a device whose mechanism consists of a valve having either a sliding or rotary movement, and

provided with a suitable admission and exhaust port, a piston operated in a cylinder, and a piston rod connected to the bell crank so as to impart a swinging movement. The motive power is air taken from the main reservoir.

There are quite a number of bell ringers in use, all of which, however, are very similar in design and construction. Some types are provided with a threaded stem and a jam nut by which ad-

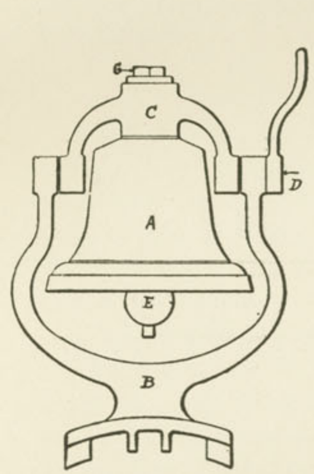


Fig. 8.

Bell and Frame.

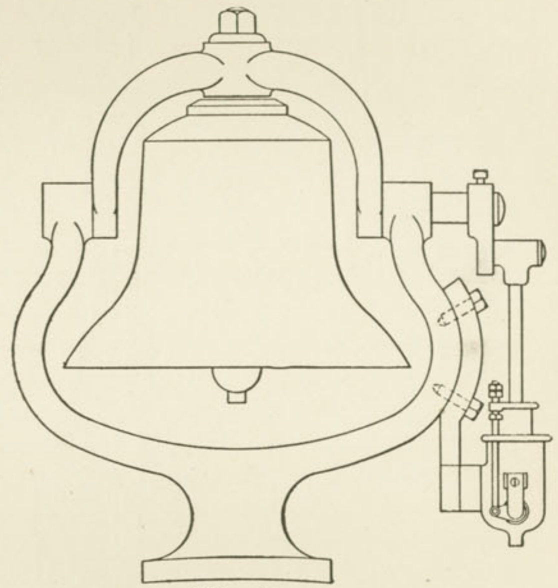


Fig. 9.

Samson Bell Ringer.

justment can be made, while others have a piston rod operating like a telescope, and requiring no adjustment.

Fig. 9 shows the exterior view of the "Sansom" bell ringer. It has no packed joints except the piston, which has a heavy leather packing. The valve is a plug cock held to seat by a coiled spring. The weight of the bell compresses the air in the cylinder on the down stroke, so that it only requires a small amount of air from the air system to lift it on its upward stroke. By controlling the amount of air supplied to the piston, any speed of ringing may be obtained.

A sectional view of the Gollmar bell ringer, which has been adopted on many of the leading railroads in this country, is shown in Fig. 10. The feature of this device, is the automatic starter, which may be worked by steam taken from the boiler or by air from the air brake. It can be used to ring the bell continuously,

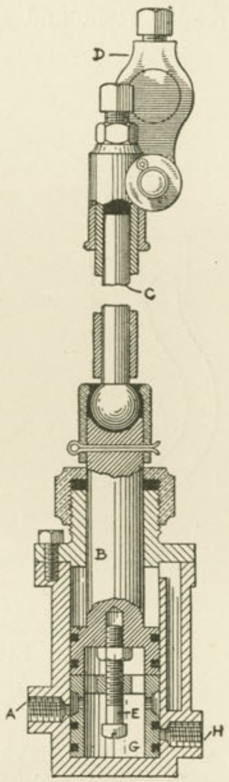


Fig. 10.

Gollmar Bell Ringer.

or it may be run at intervals as desired. The automatic starting device causes the bell to ring immediately upon sounding the whistle. The operation of the Gollmar bell ringer is as follows: Pressure is admitted through the upper opening A, admitting the pressure under the single acting piston B. This causes the piston

to rise, forcing the bell to swing. The connecting rod is shown at C, and is so constructed as to allow the crank D to make a complete revolution without causing the piston C to move. When the ringer is started to work, the piston C will be driven upward, causing the bell to swing, and the valve stem E will raise the valve G, closing the inlet port A, and the air in the cylinder is used expansively. On the downward stroke, the piston B comes in contact with valve G, closing the exhaust port H, and opening the inlet port A, after cushioning on the pressure remaining in the cylinder.

HEADLIGHTS.

A locomotive headlight is a large lamp placed in front of a locomotive to give warning of its approach at night, and also to illuminate the track in front of the locomotive. The usual form of headlight is shown in Fig. 11, in which A is the lamp case; B, the reflector; C, the glass; D, the chimney; E, the burner; and F the reservoir.

The headlight case is generally put on top of the front end of the engine, or fastened to the front end ring with suitable brackets. The former location is probably the more satisfactory because of its being more accessible. This, however, is governed by the size of the front end, length of stack, etc. The headlight case is generally twenty-three inches wide, thirty-four inches high and sixteen inches deep. This allows the use of an eighteen-inch reflector. The case should be raised from the base about one inch by strips under the end, to admit air for circulation. There should be three one-inch holes through the bottom. The door should be on the left side of the case, and should open towards the front.

When transparent numbers of engines on the sides of the case are used, porcelain glass, with the number of the engine cut out of sheet steel and slipped over it, has been found satisfactory. Ground glass shows well when clean, but it is too easily soiled. The inside of the case and the back of the reflector should be painted white and kept neat.

Headlight Cover. The rules call for covering the headlight when the train is on a siding, expecting to met opposing trains, and there are quite a number of devices in use for this purpose. The curtain outside of the case has not been found satisfactory, because it is affected by severe weather, and the curtain inside of the case has not been found perfectly satisfactory. A headlight cover which has proven durable is sheet iron held in place over the glass by three lugs on the edge of the bissell. The number of

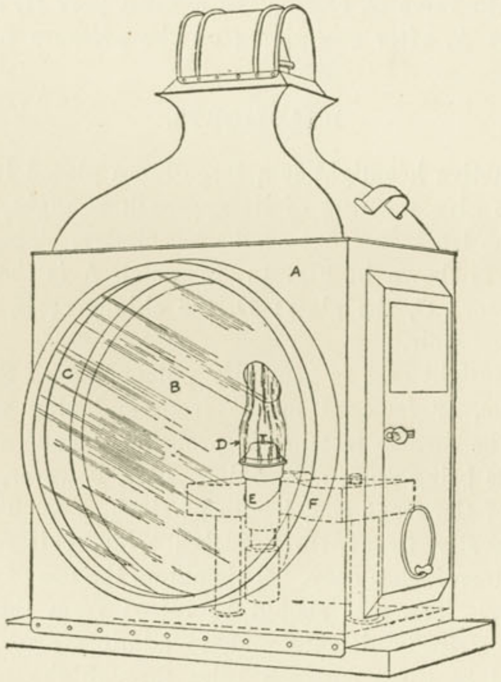


Fig. 11.

OIL HEADLIGHT.

the engine is outlined in this cover by perforating it with one-sixteenth-inch holes. When the number of the engine is entirely cut out it is often misleading, as the light shines through, making it appear that the headlight is not covered. When not in use this sheet iron cover is carried on the back of the case in suitable brackets.

On every engine, the headlight case should be set parallel with the boiler, and the back of the reflector should be adjusted so that the front edge will be parallel with the front edge of the case.

Reflectors. The reflector of a headlight is used for properly concentrating the light and throwing it on to the track ahead. To focus the light, the locomotive should be on a straight track; then move the lamp or reflector until a perfect beam of light is drawn together.

The back side of the reflector as well as the inside of the case should be painted white. The headlight on an engine must be kept clean, not only the inside of the case and the back of the reflector, but also the glasses and reflector.

Types of Headlights. Headlights at the present time may be divided into three types according to whether they use oil, acetylene or electricity.

Oil Headlights. In the oil headlight, the burner is usually perforated so that air may be admitted to the flame. The principal precautions necessary with the use of this type of headlight are cleanliness and proper adjustment. To properly adjust the wick, it should be so set that the cylinder cone divides the holes through the sides of the burner. To spread the flame the button should set about five-eighths of an inch above the top of the burner, and care must be used to see that the brace that holds the top of the chimney is set so that it will hold the flue flat on the burner and not allow air to pass under it.

Acetylene Headlights. To supply the demand for a locomotive headlight that will throw a ray of light a considerable distance and at the same time be economical in operation, the acetylene headlight has been devised. It is claimed that the acetylene headlight does not give the same blinding effect as the electric light, but gives a more mellow light, which is just as penetrating. It can be equipped to any oil headlight by replacing the oil lamp with an acetylene, which obtains its supply of gas from a tank placed on the side or front of the locomotive.

The arrangement of connections, as used in the Safety Storage System, is shown in Fig. 12. The acetylene gas is contained in cylinder A, at a pressure of 150 pounds per square inch, and at this pressure contains 150 cubic feet of gas. It is thence piped, by means of piping B, to the filling valve C, the gauge D, and the regulating valve E. Up to this point, there exists the high pressure of cylinder which is shown by gauge D. The regulating valve E reduces this pressure to $2\frac{1}{2}$-in. of water, which is the United States standard burning pressure of acetylene. The gas is led from regulating valve E, by means of $\frac{1}{8}$-in. pipe, F, F, through the handrail and thence to the headlight, H, which is equipped with a $\frac{3}{4}$-foot burner.

The operation of the light is very simple, the gas being merely turned on at the cylinder and lighted in the usual manner, care being taken, however, to have the door of the lamp open

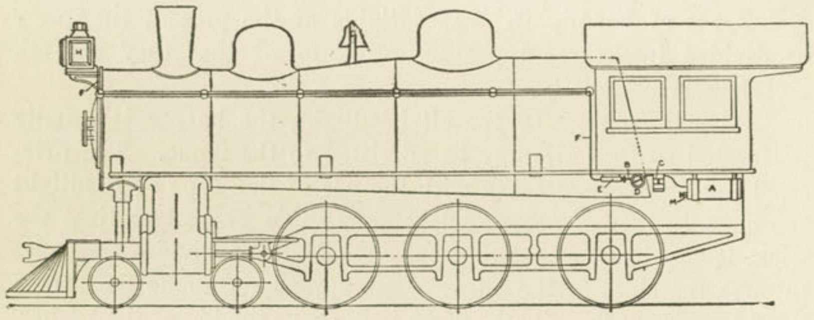


Fig. 12.

Acetylene Headlight System.

when the gas is turned on. In order to put it out, close cock in the headlight.

When the cylinder is exhausted, it may be either replaced with one that has been charged, or it may be recharged from a charging plant by using the filling valve, C, the pressure contained in the cylinder being shown on gauge D.

When applying an acetylene headlight equipment, attach the cylinder to running board of engine, or under overhang of cab on fireman's side, by means of bolts and straps. All high pressure threaded joints should be tinned and soldered, and the piping firmly fastened in place. The regulating valve should be held in place by bolts through running board or cab flooring. All

threaded joints in the low pressure piping should be coated with black asphaltum before being screwed into fittings. The connection between the piping and headlight is made by using a piece of extra heavy rubber tubing, which is slipped over the hose connection at base of burner riser and at end of low pressure piping, and is wired firmly over nipples. All pipe work should be

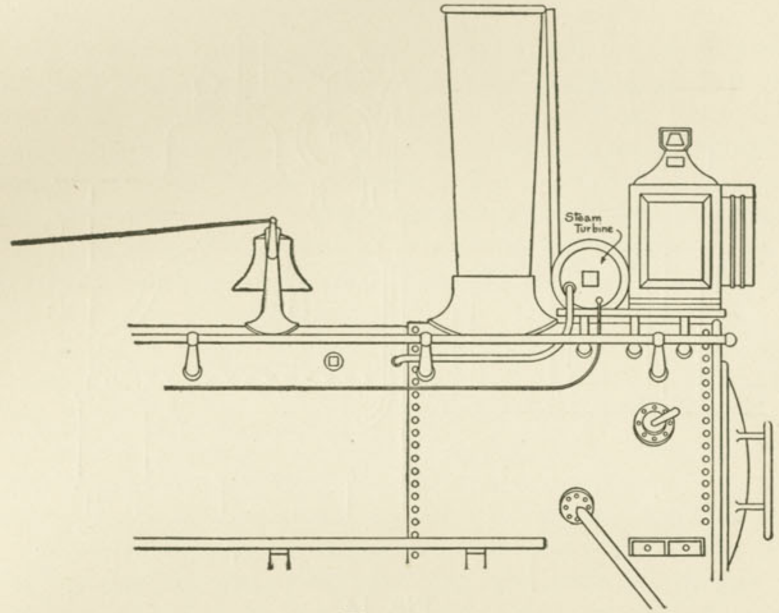


Fig. 13.

Front Location of Steam Turbine Used With Electric Headlights.

tested by applying soap suds to the joints. Do not test for leaks with a torch or light of any description.

When first throwing gas pressure on the system, open stud valve, M, slowly, and after the gauge, D, has recorded full pressure the valve M should be opened wide.

Electric Headlight. In order to overcome the disadvantages of the oil headlight and to obtain a light which will be projected far enough ahead to enable the engineer to see any impending danger in time to stop, or at least to considerably slacken the speed, the electric headlight has been designed. It has met with considerable success, and is being used extensively for both freight and passenger service on many Western roads.

The equipment for an electric headlight consists of a steam turbine, a dynamo, the proper wires, the focusing arc lamp and a specially designed headlight case and reflector.

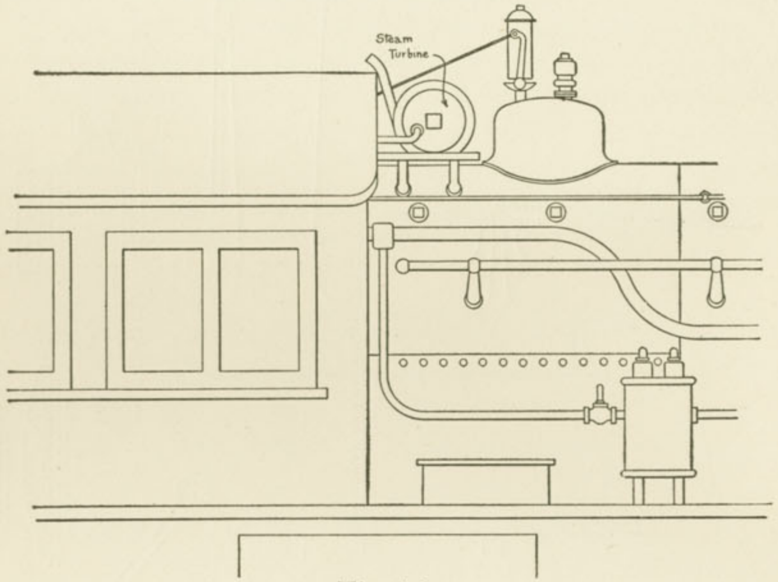


Fig. 14.

STEAM TURBINE EQUIPMENT FOR ELECTRIC HEADLIGHTS LOCATED IN FRONT OF CAB.

The generating device may be located either on the front end of the engine forward of the stack, as shown in Fig. 13, or it may be located on the boiler just in front of the cab, as shown in Fig. 14. The headlight, of course, in any case, occupies its usual position at the front of the locomotive.

Types of Electric Headlights. There are three types of electric headlights manufactured, the Pyle the Edwards and the Schroeder. The two former types are, however, in most general use.

Edwards Electric Headlight. The Edwards electric headlight equipment consists of four parts; first, the motor, a simple-acting steam turbine; secondly, the dynamo, mounted on the same axle with the turbine and designed to yield to the arc light a current of from 30 to 33 amperes and from 30 to 33 volts; thirdly, the lamp, including the arc, the deflectors and the case; and fourthly, the bed-plate on which the whole apparatus is mounted.

The motive power for the Edwards electric headlight equipment is produced by a steam turbine. The steam passes through the governor balanced piston valve; after passing through this valve the steam enters the nozzle; passing through the nozzle it enters the wheel buckets, and is discharged on the opposite side of the wheel, passing through the exhaust port, then through the balancing ports to the exhaust opening, and from there discharging into the smoke arch. For different boiler pressures different sized nozzles are used.

The steam turbine is provided with a propeller wheel, which is constructed of rolled steel. It has a normal speed of about 2,000 R. P. M. The speed of the engine is held constant, or practically so, regardless of change of load or initial pressure, by a governor, which is so arranged with relation to the other parts of the engine as to be accessible. All the moving parts are encased in a cast-iron housing, so designed as to thoroughly protect it from the elements, dirt, dust, etc. The lubrication is automatic, and is provided by loose rings feeding the oil to the ball bearings from the oil wells.

The dynamo is of peculiar construction, designed for the particular purpose for which it is used. The field is differentially wound, and the electric circuits so arranged that a burned-out armature is impossible. Should a short circuit occur on any point of the circuit, the current is neutralized, and no matter how long the engine may run or the armature rotate, there will be no production of current whatever until the short circuit is removed. As soon as this is done the dynamo performs its proper functions and operates as usual. The current densities throughout the whole machine are very low, so that a minimum heat effect is produced, regardless of extremes of temperature, or other conditions which might affect the resistance of the machine. Low-resistance carbon brushes are used. Very large and long journal bearings are provided, and profuse lubrication is secured through the medium of loose rings dipping into the oil wells. An important feature of the equipment is the arc lamp with its parabolic reflector. It is strongly made, and care has been taken to insure a steady and constant light, free from flicker.

The vertical beam is caused to project upwards by an auxiliary plane deflector, placed outside the goggle at an angle of 45°, and in such a position as to intercept about 40 per cent of the whole volume of light issuing from the parabolic reflector and direct it vertically. This vertical beam forms a constant warning signal, reaching to a great height, and on cloudy nights when striking the clouds, it can be seen for many miles.

The whole apparatus is generally mounted upon one cast-iron bed plate, which is secured at the proper place on the smoke arch by means of brackets bolted thereon. The other connections consist of a three-quarter-inch live steam pipe from the cab, and the passing of a one and one-quarter-inch exhaust pipe into the smoke arch.

The flow of current through the arc lamp is regulated by shunt coil and series coil, as can be seen from the diagram supplied by makers.

The shunt coil is always in circuit with the armature and field shunt of the dynamo. The circuit through the lamp series coil, and field differential coils, is held open at the carbon point by springs, when the dynamo is not in operation. When the dynamo is started, the current flows through the shunt coil, and draws down the soft iron core suspended on the equalizer; this releases and breaks the engagement between the pawl and escapement wheel, thus permitting the brass column or oil cylinder to fall until the carbon point comes into contact with the copper negative. The instant this occurs a circuit is established through the series coil, and its iron core draws down the equalizer, thus establishing the arc.

It is always absolutely necessary that the leads from the dynamo to the lamp be so connected as that the current shall flow from the carbon to the copper negative. If the current be

reversed, so as to flow from the copper negative to the carbon, the negative will be fused, giving to the light a greenish color. To prevent this the wire cable leads, where they connect to the lamp binding posts, are provided with brass plugs of different diameters, and the holes in which they are inserted in the binding post are of suitable diameters, so that the connection at this point cannot be reversed.

To adjust the lamp, first have the correct speed on the dynamo, and the commutator and brushes working properly, then set the adjusting screw on the shunt side of the lamps so that the pawl will clear the escapement wheel about 1-100 of an inch; then raise the brass tube, or oil cylinder, which carries the carbon by means of the carbon holder support, and permit it to fall; then adjust the limit screw, so that when the arc is established it will hold over without breaking the circuit. If the arm breaks when the light is started, or if, while the light is in operation, the equalizer sets up a pumping action, giving a vibrating or flickering light, the limit screw is set too high.

On the other hand, if this limit screw is set too low, there will not be sufficient separation, when the light is started, and there will be only a small red light. This also may occur when the light is in operation and the locomotive in motion, which defect may be easily and quickly corrected by slightly raising this limit screw. When the arc is properly established, the spring should be adjusted by means of the nuts, so that the carbon will feed as it burns away without breaking the arm. If "tack head" deposits form on the top of the negative, and, breaking off, interrupt the light occasionally, it is evident that the spring is too weak, thus not allowing the arc to be drawn out long enough. A slight increase of the spring tension by adjusting the nuts will correct this fault.

It is necessary that the brass tube, or oil cylinder, guide rod, and valve rod should be kept perfectly clean. For this purpose a soft felt cloth should be used, never using sandpaper or emery paper or waste, as the sand and emery will roughen these surfaces, and the lint from the waste may clog the rack, thus preventing the carbon from feeding properly. The engagement between the rack and pinion should be as close as possible to prevent any lost motion, and yet permit the brass tube, or oil cylinder, to fall freely; this adjustment is effected by means of screws, the flat spring having oblong holes through which these screws pass.

The descent of the brass tube, which carries the carbon holder, should be occasionally tested to see if it is feeding at its proper speed. To do this, remove the carbon and raise the brass tube, or oil cylinder, to its upper limit, then press down the equalizer and permit the column to fall. It should fall its full distance in not less than 1¾ minutes and not more than 2¼ minutes. The time of falling is governed by the flow of kerosene through the valve, and if the time is longer or shorter than above mentioned, it is due to dirt in the hole or under the valve seat. It is therefore essential that the valve should always be perfectly clean. The oil cylinder is filled with kerosene oil, and there may be slight evaporation which may reduce the quantity below the proper amount. This may not occur for six months or a year, but when it does occur it is shown by the oil cylinder suddenly dropping a fraction of an inch when at the bottom of its stroke, and when the carbon is nearly consumed. Should this happen, remove the lamp from the case and fill the oil cylinder with the best, clean kerosene oil.

The negative is made of rolled copper rod, and the position of its point determines the focal point of the arc in the reflector, hence it always is necessary to set the negative with the aid of the gauge, which is chained to the lamp.

When the point of the negative becomes flattened, concave or rough, it should be removed and dressed to a point. In replacing the negative be sure to clamp it firmly.

To adjust the equalizer weight, remove the lamp from the case so as to be able to shake it violently; disconnect spring so that it has no tension on the equalizer; insert about six inches of carbon in the holder, and permit its end to project through the guide, but not to come into contact with the negative. Set the weight so that the pawl will be just on the point of releasing the wheel, but will not do so when the lamp is violently shaken and roughly jarred in any direction.

The lamp and reflector are adjustable in all directions with relation to each other. To properly focus the lamp in the reflector, place the locomotive on a straight track, facing a stretch at least a mile long, and shift the lamp and reflector until a perfect parallel beam can be drawn without any crossing of the rays, which produces dark spots. When the focus is properly located on the track, the engineer should be able to see at least a mile ahead of his engine.

One feature which distinguishes the Edwards system of headlighting is the vertical beam of light, which is produced by arranging a plane reflector (mirror) outside the goggle in such a position and at such an angle as to intercept about one-third of the whole volume of light and throw it skyward in a perpendicular shaft. Aside from its undoubted spectacular quality, this vertical beam appears to have a real value of considerable importance, especially on steep grades or in hilly country where the track is winding. Under such circumstances, where conditions are at all favorable, this aerial shaft of light serves as a signal which can be seen for a considerable distance, for many miles even, when the atmosphere is unfavorable.

Pyle Electric Headlight. Differing only slightly from the other types of electric headlights in use is the Pyle electric headlight. The equipment of this apparatus consists of a steam turbine, dynamo, lamp and three incandescent lights used in the cab.

The engine is known as the Pyle compound steam turbine. There are no wearing surfaces inside the engine requiring lubrication, hence it does not use any sight feed lubricator in the cab. Before starting the engine be sure the casing is thoroughly drained, and do not turn on steam too suddenly in starting the light, thus allowing time for the condensation to get out of the engine. It must have dry steam.

Remove plug in top of engine once each week and pour in a little black oil. This will prevent corrosion of parts. The inside bearing only needs enough oil in the well for the loose ring to touch the oil and carry up on top of the shaft. If there is too much oil, it will be thrown out of the ends of the cellar by the motion of the locomotive, which may ruin the armature. The oil well for the outside bearing should be filled each trip. Use valve or cylinder oil in these bearings.

The dynamo is constructed on scientific principles, so that no sparks should be seen at the brushes. The armature is held in place on the engine shaft by one screw, which can be easily taken out if occasion demands. The brush holders are fixed, and the brushes can be taken out and replaced without changing the tension of the springs. A graphite brush is used for the top and a carbon brush for the bottom.

The mica between the copper strips of the commutator should always be a trifle below the surface. If it gets too high, file it down with a small file. Do not get it too low, as it will collect dirt, etc., and cause a short circuit. The commutator should be cleaned each trip with a damp piece of waste (not wet), rubbing endwise so as to keep the creases clean where mica is filed out.

Be sure to have the brushes fit perfectly on the commutator. If there is poor contact brushes will spark. If commutator is running out, or has the appearance of getting rough, clean it up. To do this nicely, remove the brushes and hold a strip of No. 0 sandpaper on the commutator while running. Don't press the sandpaper on, for if there are any low spots they will increase in size.

If the brush tension spring is too tight, it creates friction, heat and unnecessary wear both on the commutator and the brushes. If too loose it will spark and the commutator will not run clean. Have it put tight enough to prevent sparking. In this case a little judgment must be used, for if the brushes are not in the proper condition, or commutator smooth and true, there will be sparking at the brushes, no matter how much pressure is used. Do not forget that the commutator is the vital part of all dynamos, and none will run successfully without regular care and attention. The voltage of the dynamo is entirely too low to force a current through any portion of the human body, so that it may be handled freely and without any possible fear of being injured by it.

If the commutator becomes rough or out of round, it should be trued up in a lathe. The tool used must be very sharp, and light cuts must be taken, then polish it with fine sandpaper. It must be carefully examined to see that no two sections touch, as the copper is liable to lag or burr from one section to the other; and before putting it back, it would be better to cut or file the mica (between each section) a little below the surface, for it does not wear away as fast as the copper, and if the mica is not cut away it may lead to sparking. After doing this, be sure no ragged edges of copper stick up, for this will cut away the brushes rapidly. The speed of the armature should be as near 1,800 revolutions per minute as possible, unless the copper electrode burns off, when it should be reduced until the copper electrode does not burn.

To trim the lamp in the dark, it is much better to remove the top carbon holder from the slide. After securing the carbon in the holder, take it between the thumb and forefinger and with the remaining fingers resting on the guide put it in place. If desired to clean the reflector, remove only the top guide by loosening the thumb nut at the end of the upper arm, then remove the guide carbon and carbon holder.

The tension spring in the lamp is for two purposes. It brings together the points of the carbons, so as to establish the arc when the dynamo is set in motion, for there must be a complete circuit before there is any current. If the carbons are separated only a small fraction of an inch, the lamp will refuse to work, because the current will not jump across the separation. Sometimes there will be a deposit of scale on the point of the lower copper electrode, which prevents the top carbon touching the copper, and as the current will not go through this scale there will be no light until it is removed. See that the point of copper is clean before each trip. Suppose all wires are connected and the lamp properly trimmed, turn on steam and set the armature in motion. The current enters the lamp, and, passing through or around the solenoid magnet, draws down the iron armature. This in turn separates the carbons, thus forming the arc or light. It will be noticed that the spring is secured to the end of the lever toward the carbons, or on the opposite end from the magnet, and pulls against it. This prevents the solenoid from pulling the carbons too far apart. The volume of light will depend largely on the way this tension spring is regulated. It may be so tight that the magnet will be unable to separate the carbons, consequently there will be no light. If the dynamo is run too long with the lamp in this condition it will burn out the armature or the field, for the current becomes very heavy.

If the tension spring is very loose, the lamp will flash and go out, for the magnet will be drawn down too far. When the light goes out the current is broken, and there being no strength in the magnet, the spring will again bring the carbons together, then the current is instantly reestablished. Adjust the spring so that the lamp will flicker just a little, when the locomotive is at rest.

The wires leading back to the incandescent lamps may come together causing a short circuit. This will put the light out. When this occurs the dynamo will be generating a heavy current, the speed will be quite low, and there will be a small light in the lamp. In this case disconnect one of the small wires from connecting screw, then look for the cause of the trouble.

Schroeder Electric Headlight. This type of electric headlight equipment is small and compact. It is arranged for a speed of 4,000 revolutions per minute. The lamp consumes from 25 to 30 amperes of current at 30 volts, and develops upwards of 3,000 candle power without reflector.

The generator is compound wound, and incandescent lamps are used in the cab and in the headlight case to illuminate the signal numbers. These incandescent lights, being on a circuit separate from the arc light, are controlled by a separate switch. With these switches in the cab, either or both, the arc and incandescent lights can be operated separately, or together. This gives complete control of the lights from the cab, and avoids the necessity of screening the headlight. It also has quite an advantage in running through yards, standing on switches, or in stations, enabling the engineer or fireman to adjust his lights to various conditions, as they arise from time to time, without leaving the cab.

ELECTRIC HEADLIGHT SUGGESTIONS.

Most of the troubles are traceable to the adjustment of the lamp.

The magnet yoke may travel too far sometimes, and strike the small lug on frame of lamp before carbons are separated sufficiently to make a proper arc. In this case the wire should be shortened so that the magnet yoke is about halfway down before the clutch grips carbon.

If the wire is too short, the lamp will jump or the carbon will stick in the clutch.

If the carbon feeds too fast the top clutch spring is too weak and should be given more tension. To do this, remove cotter pin and get top-clutch spring out of casing. Then pull it out a little, thereby giving it more "set."

If the light burns green the dynamo is running too fast, and the speed should be reduced.

This can be stopped on the road at once by throttling the steam in the cab. There is another reason for light burning green. The main wires from the dynamo to the lamp may be connected wrong, therefore one wire should have a sleeve on each end large enough to prevent its going into the binding post with the small hole. The other wire should have plain ends.

The lamp can be moved in all directions for focusing. To get the proper vertical focus on the track, either to have the light close to you or to strike the track far ahead, loosen the set screw on the side, and by turning the adjusting screw the lamp can be raised or lowered as desired. To move it sideways, backward or forward, loosen the hand nuts and the lamp is free to move.

When once in focus there is no need of changing it again. Tighten all screws.

The back of the reflector is supported by an adjustable step, with a screw to raise or lower it, so that the volume of the light will come out in parallel lines.

Suggestions for Focusing. Adjust back of reflectors so that front edge will be parallel with front edge of case.

Adjust lamp to have point of copper as near center of reflector as possible.

Have carbon as near center of chimney hole in reflector as possible.

Have locomotive on straight track, and move lamp until best results are obtained on track. The light should be reflected in parallel rays and in as small a space as possible.

To lower light on track, raise lamp. To raise light on track, lower lamp.

If the light throws any shadows it is not focused properly.

If light is focused properly and does not then strike center of track do not change focus, but shift entire case on base board.

Point of copper should be about one inch above top of holder. If it is higher than this there will be too much heat on clutch.

Suggestions for Roundhouse Men. A centrifugal brake is placed on back side of spoke of wheel, and should be set so as to act at about 100 revolutions per minute more than where the governor acts, so that, if for any reason, the governor fails to act, this brake will check the speed and hold it at any speed at which the brake is set. The application of this brake commences with equipment No. 2,600, but cannot be applied to equipments with serial numbers lower than that.

To adjust centrifugal brake, remove the armature and cap to the engine, pull out wheel and shaft, when there will be free access to brake. If it is desired to adjust brake so that it will act at a higher speed, turn nuts to the right, being sure to adjust both brakes the same, then tighten up jam nuts. One-half turn of the nut will change the speed at which the brake will act about 150 revolutions.

The governor should be examined once each month, and if the plungers are found cut, they should be ground in or faced off as the case requires. If plungers are cut, the engine may run away and be broken by centrifugal force. If plungers are faced off, the ends of governor yoke should be bent further out from face of wheel, thereby allowing plungers to again seat firmly before governor weights are thrown out further than at right angles to face of wheel. If the speed is too high, adjusting screws should be turned back half a turn each, being careful to adjust all the screws the same. Half a turn of these screws should change speed about 100 revolutions per minute. If by turning back governor spring adjusting screw the speed is not reduced, the plungers do not seat, and should be faced off.

Suggestions for Engineers. Have a few strips of No. 0 sandpaper, about $1\frac{1}{2}$ in. wide to clean up the commutator.

If the light fails to burn when turning on steam, see that all screws are tight, and that point of copper electrode is clean. Push down on lever and see if carbon lifts up and falls freely. Put a carbon across both binding posts, and if there is a flash when it is removed, dynamo is all right, and the trouble is in lamp. If there is no flash when carbon is removed, take out brushes and clean commutator with sandpaper (not emery paper), put the brushes back and try the carbon again.

Keep all screws tight.

After putting in a new carbon, always push down on lever, and notice if carbon lifts and falls freely. If it does not lift, it is not in the clutch. If it does not fall down freely, turn it partly around and find the freest place.

The carbon should burn from eight to nine hours.

Engineers should be held responsible for the proper care of the equipments, unless some one is appointed to examine and care for them at roundhouses.

Before leaving on a trip the equipment should be started and brushes examined as to tension of springs, and adjusted if necessary before getting out on the road.

These equipments are not automatic, and as there are quite a number of enemies to electricity on the locomotive, such as grease, dirt, jar, heat, etc., it is necessary to give it a few minutes' attention each day.

Don't attempt to remove reflector from the case until the top carbon holder is removed by loosening thumb nut.

If the copper electrode burns off, equipment is running too fast, and the speed should be reduced by turning governor spring screws to the left until the trouble is stopped. Be careful and adjust all screws the same, as nearly as possible. One-half turn of screws will change speed about 100 revolutions per minute.

Be sure to adjust tension spring as loose as possible, and not have the light go out while locomotive is standing still.

If light dies down when locomotive is running fast, the tension spring may be too tight, which prevents solenoid from separating carbons sufficiently to form proper arc, or top-clutch spring may be too loose, allowing back edge of clutch to be jarred up and release carbon.

If the light goes out when the locomotive is standing still, the tension spring may be too loose or carbon may not feed freely.

If electrode does not come in line with the carbon, the holder should be bent until electrode comes in line with top carbon.

If light burns green on the road, throttle steam at once.

Both ends of one lead wire should be doubled about one inch, so that it cannot go into binding post with the small hole, and thereby prevent crossing of wires.

Special motor brushes should be used with the improved brush holders, top and bottom brush being of the same quality. The graphite and carbon brushes used with the old style brush holders should not be used with the improved brush holders, nor special motor brushes in the old style holders.

Objections to Electric Headlights. Among the objections that have been raised to the use of electric headlights on locomotives is this one, that owing to the very brilliant light, the engineer would not be able to distinguish the different colored signals, but practical experience seems to refute this idea.

Another objection is, that on a double track road there is danger of blinding an approaching engineer. There is a good ground for this latter objection, and to guard against this contingency, the apparatus is provided with a translucent shade within the goggle, which may be drawn at will by the engineer when he is at the proper distance from an approaching engine. This shade destroys the strong glare of the light, giving the effect of frosted glass. As soon as the approaching train is passed the engineer releases the shade, and again gets the full value of the light.

Electric Headlight Failures. At least fifty per cent. of the electric headlight failures are due to the improper manner in which the carbon is applied. Carbons are molded, and sometimes it is found that there is a little more stock at one point than another. When the arc is formed and the carbon is burning away, the arc gets larger, and less current passes from the carbon to the electrode. The corresponding amount circulating in the solenoid tends to weaken the magnetic pull on the levers and clutch that are suspending the carbons, and at a certain point it grows weak enough to release the latter, when it feeds down or falls of its own weight. If this carbon is a little rough or out of round, it will be held up so far away from the electrode that the current cannot flow across. Then the circuit will be broken, and the light will go out.

When applying new carbons, remove the top carbon holder from the lamp, then replace the carbon in the clamp, return carbon and clamp to the holder, release it and note if it will fall freely of its own weight and entirely through the clutch. If it will not, then turn the carbon around until a position is found in the clamp where it will, then return holder to the lamp, and it will be found that it will not be necessary to "jar" the lamp, which will sometimes remedy this trouble. The point of the carbon must be set true over the point of the electrode to get a good arc.

REVIEW QUESTIONS.

LOCOMOTIVE ACCESSORIES.

1. When and under what conditions should sand be used on a track?
2. Describe the general arrangement of a sand-box?
3. What are the particular advantages of the sanding apparatus?
4. Name three different kinds of sanding apparatus with which you are acquainted.
5. Describe briefly the construction and method of operation of the Leach "A" sander.
6. What is the greatest trouble encountered when sanders are used?
7. Give the method of operating the Nathan sander.
8. When should double and triple sanders be used on locomotives?
9. Of what use is a bell on a locomotive, and when should it be rung?

10. Why are automatic bell ringers used?

11. Describe briefly the principle of operation of the Sansom bell ringer.

12. Of what use is a locomotive headlight?

13. Of what use is a reflector on a headlight?

14. When should the headlight on a locomotive be covered at night?

15. Name three different kinds of headlights which may be used on a locomotive.

16. What are the principal objections to using an oil headlight?

17. Describe briefly the acetylene headlight system.

18. What are the particular advantages of the electric headlight?

19. When an electric headlight is used, where is the generating device usually located?

20. Name three different types of electric headlights with which you are familiar?

21. Describe briefly the construction of the turbine as used on the Edwards headlight.

22. How is the lamp adjusted on the Edwards electric headlight?

23. What is the particular feature which distinguishes the Edwards system of headlight?

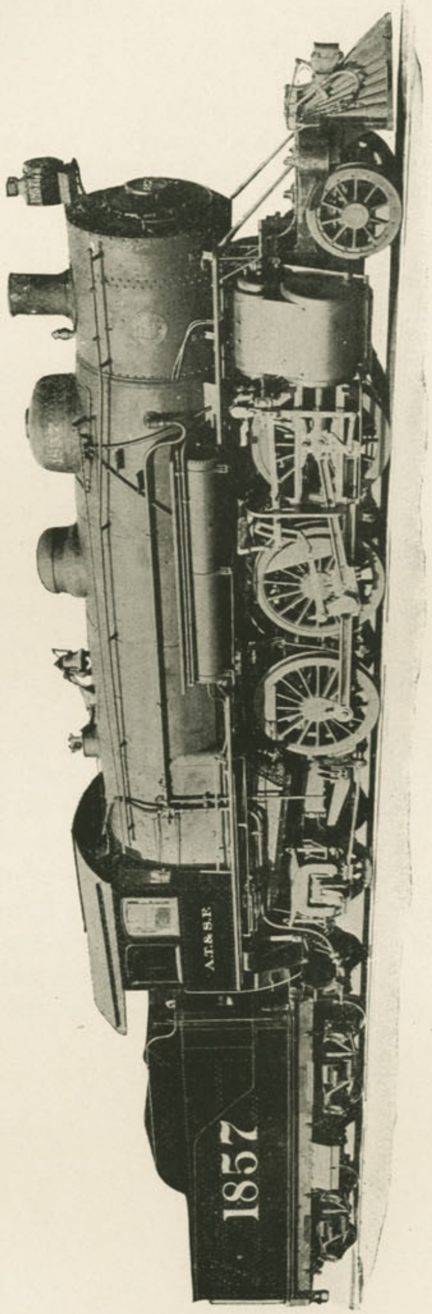
24. If the commutator of the generator becomes out of round, how should you remedy it?

25. Suppose the mica between the copper strips of the commutator should be too high, what would you do?

26. How often should the commutator be cleaned?

27. What are the principal objections to electric headlights?

28. What is the principal cause of electric headlight fail-



PRAIRIE TYPE OF LOCOMOTIVE USED FOR FAST FREIGHT AND HEAVY PASSENGER SERVICE ON THE ATCHINSON, TOPEKA AND SANTA FE RAILROAD
(Baldwin Locomotive Works)

Locomotive Tenders and Water Scoops.

Locomotive tenders are used for the purpose of carrying a supply of fuel and water for locomotives while they are running. The usual construction is shown in Figs. 1, 2 and 3, which represent the side, top and end view of a modern steel riveted tender. The frame is made of steel channel bars A, A, and is mounted on a pair of trucks B, B. The top of the frame is covered with a floor, C, C, upon which a sheet iron tank D D is placed, which carries the supply of water. It is made in a horizontal V-form, so that the space between the two legs of the V can be used for fuel. Around the upper edge of the tank a rim E, E is riveted, so as to prevent the fuel from falling off when it is filled up above the top of the tank.

Locomotive tenders are usually filled at water stations with a leather or canvas hose connected to a pipe or tank which furnishes a supply of water. The tank has an opening F on top called a "manhole," or "filling funnel," into which the hose is inserted, and a stream of water is then allowed to flow through the hose into the tank of the tender. The tank which supplies water to the tender is usually higher than the tender, and the water is generally pumped into this tank, so that it will run into the tender. To avoid frequent stops for water, express passenger locomotive tenders are usually equipped with what is called a "water scoop" for taking water while the engine is running. This consists of a bent tube, G, G, which is attached to the under side of the tank and extends up inside of it to the top. A long trough is laid between the rails, and is filled with water. The lower end of the bent tube or scoop has a joint or hinge at I, so

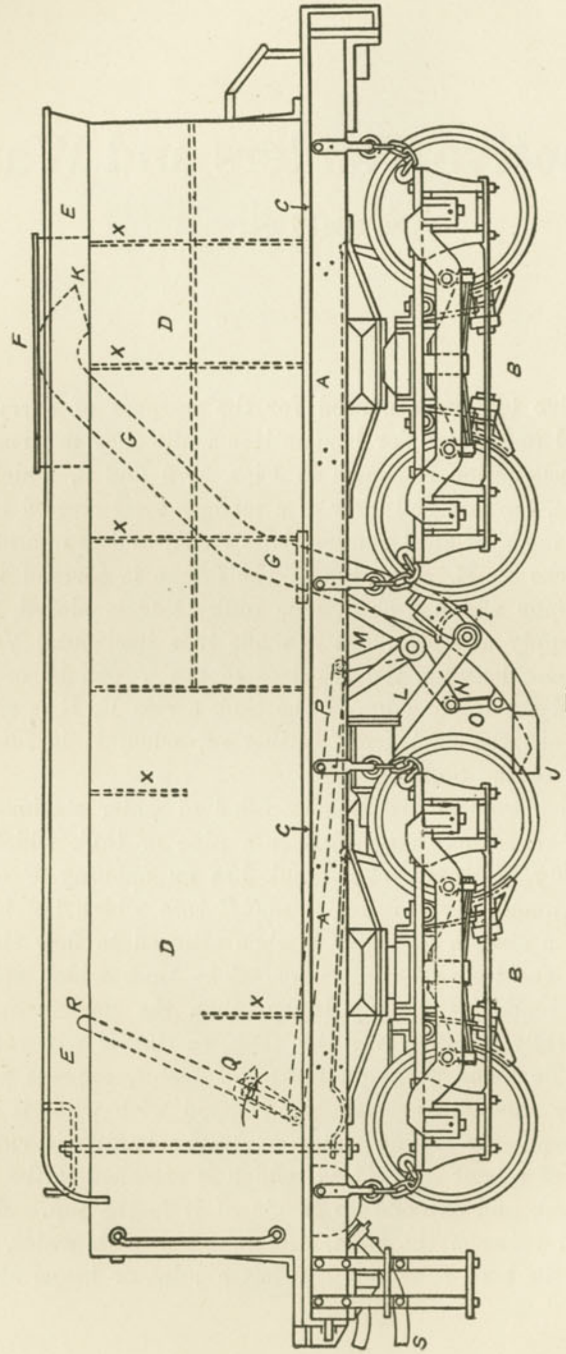


Fig. 1.

Side View of a Steel Riveted Tender.

that it can be lowered into the trough, and the lower end J will then dip a few inches into the water. The motion of the engine forces the water up the tube G, G, and it is discharged into the tank at K.

The end of the scoop is lowered into the water by means of a shaft L, which has two arms, M and N, located above the lower end of the scoop. One of these arms, N, is connected by a link, O, to the movable part of the scoop, and the other arm, M, is connected by a rod to a lever P Q R. The fulcrum of this lever is at Q, and it has a handle R at the top. By moving the upper

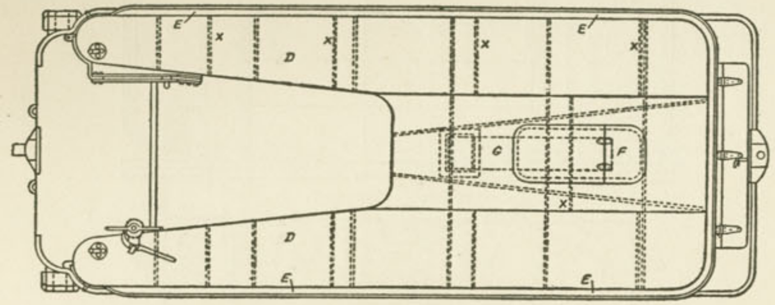


Fig. 2.

Top View of Tender.

end of the lever backward the scoop is lowered, and by moving it forward the scoop is raised.

From the water tank on the tender the water is conducted to the engine by means of a rubber hose, S, which is connected to the pipe on the engine which supplies the injector with water. This hose may be connected to the tank direct, or it may be attached to an auxiliary tank located below the main tank. The auxiliary tank is used to prevent air entering the injector when the main tank is nearly empty. The water pipe from the tender to the engine is closed by means of a valve, which closes the opening in the auxiliary tank. The valve is covered with a hood or strainer, which is used for the purpose of preventing dirt from entering the hose, and thus getting into and obstructing the pump or injector.

The interior of the water tank contains transverse plates, X X, called swash plates, which resist the movement of the water in the tank when the engine stops and starts suddenly. The sides of the tank are generally braced or stayed with rods or bars, and T-irons are also used to stiffen them.

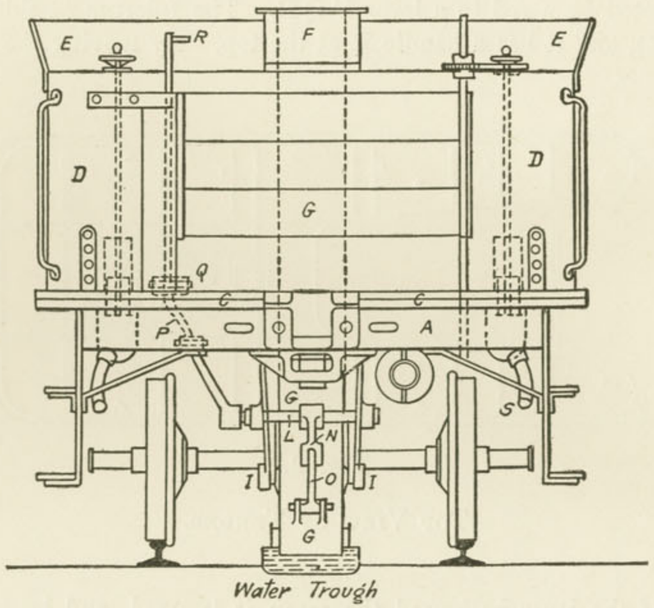


Fig. 3.

End View of Tender Showing Water Scoop.

Bearings and Axles. The construction of the axle boxes is shown in Fig. 4. The bearings are placed outside of the wheels because they can be more easily oiled and repaired. The journal of the axle is shown at A. It is enclosed in a cast iron box K, K, which is open front and back. The front has a cover H, which is either fastened by a spring or is bolted to the box. D is the journal bearing which rests against the bearing key E, which is so arranged that the brass bearing can be raised high

enough to clear the collar G, so that it can be removed. J is a dust guard which prevents dust from getting to the axle and oil

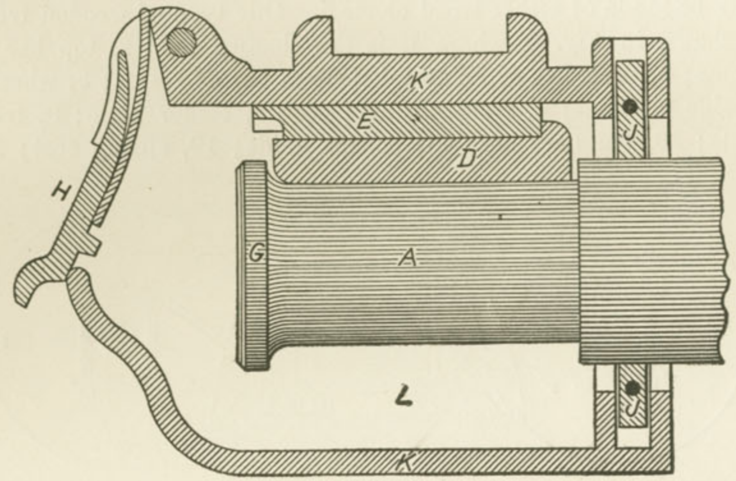


Fig. 4.

Tender Axle Box.

from leaking out. The lower portion of the axle box, L, is usually filled with cotton or woolen waste saturated with oil. This

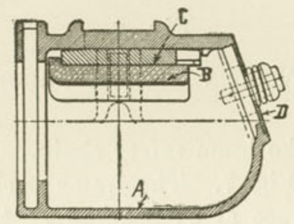


Fig. 5.

Bearing and Box for Tender Axle.

constantly presses against the axle, and thus keeps it oiled. Another form is shown in Fig. 5, where A represents the box itself; B, the tender truck box brass; C, the tender truck box wedge, and D, the tender truck box lid.

Tender Trucks. The tenders are supported on trucks, which may be made of either wood or steel. One type of wooden truck is shown in Fig. 6, where 1, is the channel bar; 2, top bar of frame; 3, truss bar of frame; 4, bottom bar of frame; 5, wheels; 6, side bearings; 7, frame-filling piece; 8, center plate; 9, truss plate; 10, truss washer; 11, bolster guide; 12, spring seat; 13,

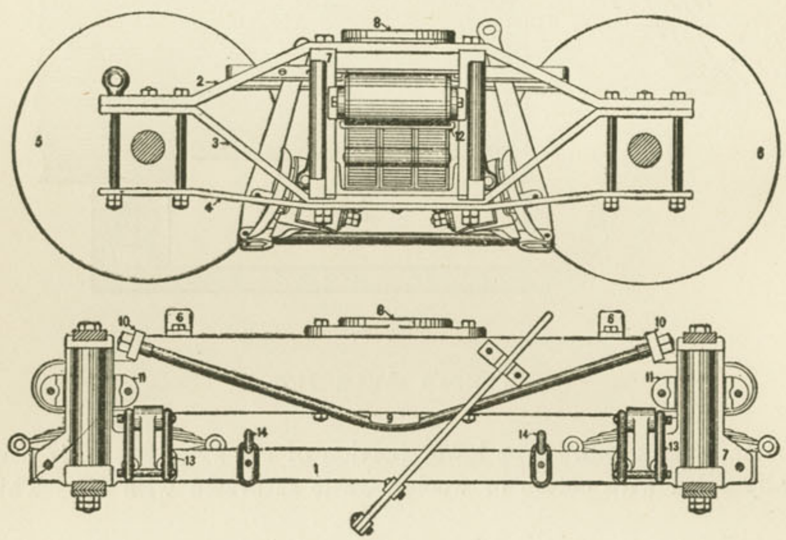


Fig. 6.

Wooden Tender Truck.

brake clevis; 14, brake beam safety chain. A tender truck made of steel is shown in Fig. 7. The frame is shown at 1; the cross-tie at 2; cross-tie brace at 3; pedestal at 4; pedestal cap at 5; equalizing beam at 6; spring at 7; spring link at 8; spring link seat at 9; center plate at 10; frame-filling piece at 11; side bearing at 12; brake hanger at 13; brake clevis at 14; safety chain clevis at 15; spring washer at 16.

Another form used on light locomotive tenders is shown in Fig. 8, where 1 is the tender truck wheel; 2, the tender truck

axle; 3 and 4, the tender truck arch bars; 5, the tender truck tie bar; 6, the tender truck center pin; 7, the tender truck bolster; 8, the tender truck bolster end casting; 9, the tender truck bolster guide; 10, the tender truck bolster guide block; 11, the tender truck spring; 12, tender truck spring plank; 13, tender truck spring plank casting; 14, tender truck side bearing.

Tender Brakes. While all locomotive tenders are equipped with air brakes, they are also supplied with hand brakes, which may be used in cases of emergency. Fig. 9 represents the usual construction of a tender brake. 1 is the shaft; 2, the handle;

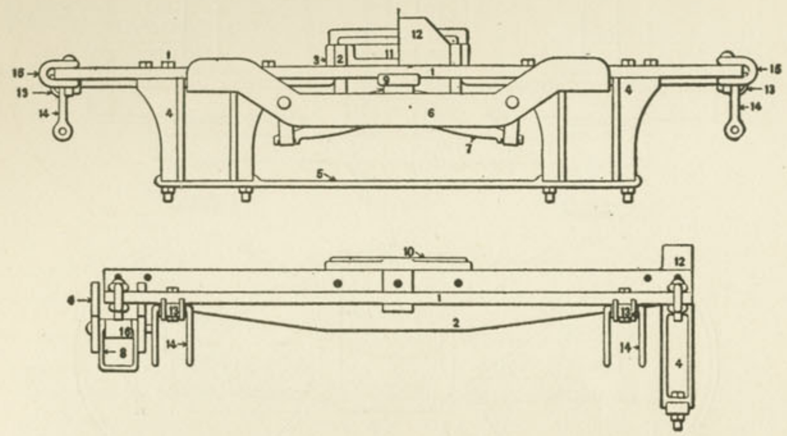


Fig. 7.

Steel Tender Truck.

3, the hanger; 4, the step; 5, the pawl; 6, the ratchet; 7, the plate; 8, the eye bolt; 9, the beam; 10, the lever; 11, lever rod; 12, lever jaw; 13, washer; 14, the head, and 15, the brake shoe.

Tender Frames. Tender frames are usually made of steel girders, which are riveted and bolted together as shown in Fig. 10. The tender draw heads are shown at 2 and 3; the tender frame center pin at 4; the tender frame chafing iron at 5; the tender frame chafing iron pocket at 6; the tender frame side bearing at 7; the tender frame push pole pocket at 8.

Tender Tanks. While the largest number of locomotive tanks are supported directly on the tender frames as shown in Figs. 1, 2 and 3, light locomotives often do away with the use of the tender, and carry their water and coal supply directly on the engine trucks. When this method is resorted to, the water tank is carried directly over the boiler, and is known as a saddle tank. A saddle tank of this kind is shown in Fig. 11, where A represents the saddle tank complete, B, the form of saddle tank cover used

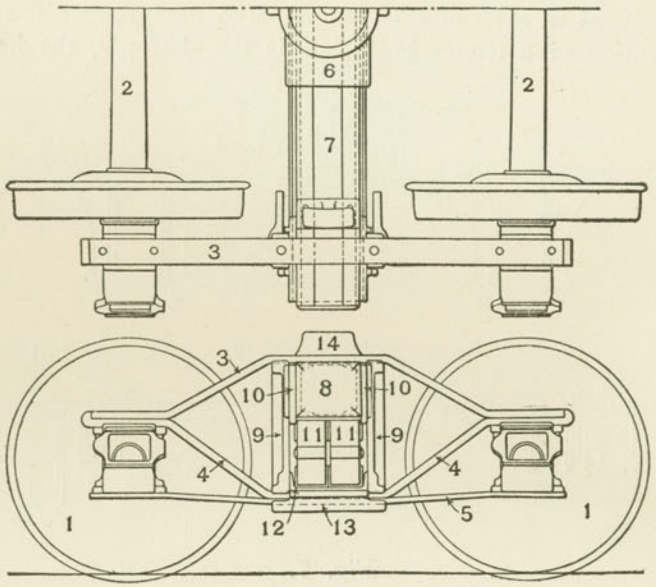


Fig. 8.

Truck Used on Light Locomotives.

when made of sheet iron, and C a form of saddle tank cover used when made of cast iron.

Tender tanks, used in districts where the water is liable to freeze, are provided with steam pipes which keep the water in the tank at a temperature above freezing. This heater generally consists of a coil of pipe of about $1\frac{1}{2}$ inches in diameter. The steam flowing into the coil is regulated by a valve located in the cab. In some instances, the coil is connected to the safety valve,

so that the steam which would otherwise escape is utilized for warming the water.

Capacity of Tender Tanks. The capacity of a tender tank varies according to the size of the locomotive and the service which it is called upon to perform. For switching engines and engines engaged in short passenger runs, the tanks are generally comparatively small. Engines used for long passenger runs or heavy freight runs require large tanks. In general practice, it

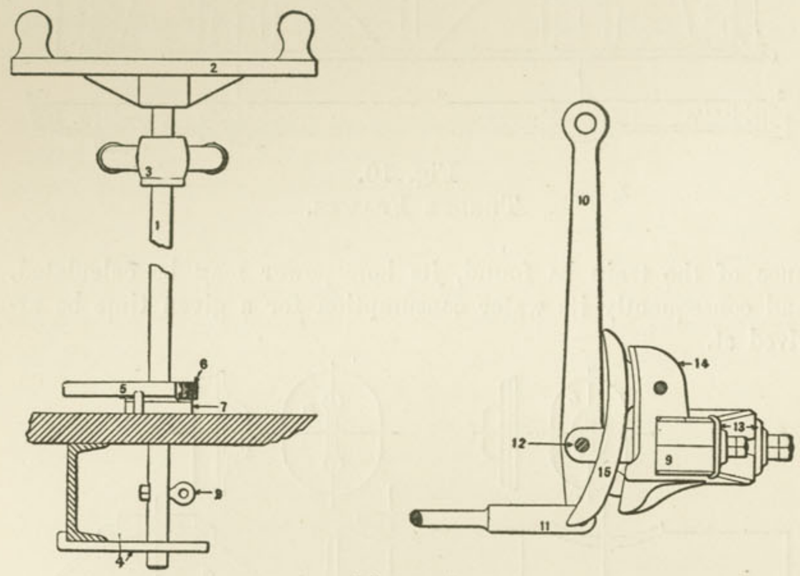


Fig. 9.

Tender Brake.

will be found that the capacity of the average tender will vary from 2000 gallons for light service to 8000 gallons for heavy service.

When calculating the capacity of the tank, the horsepower of the locomotive and the length of run must be considered. The horsepower of the engine will depend upon the weight of the train, the speed at which it is run, the size of the engine cylinders and the grades that are to be overcome. For ordinary calculations, it is usual to assume that a locomotive requires about 35 pounds of water per horsepower per hour, so that if the resist-

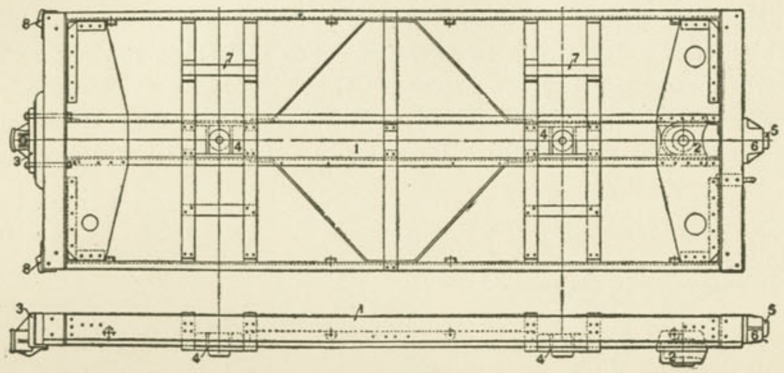


Fig. 10.
TENDER FRAMES.

ance of the train be found, its horsepower may be calculated, and consequently its water consumption for a given time be arrived at.

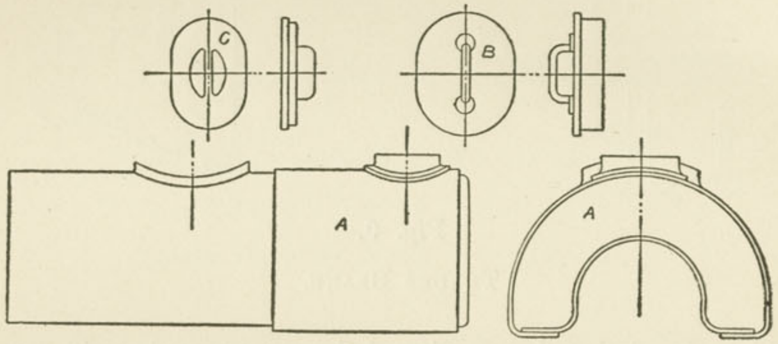


Fig. 11.
LOCOMOTIVE SADDLE TANK.

The resistance of a train may be calculated from the formula:

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

in which R=resistance of train in pounds per ton and V=velocity in miles per hour. The total resistance in pounds may be obtained by multiplying the resistance in pounds per ton by the weight of the train.

The horsepower may then be calculated from the formula:

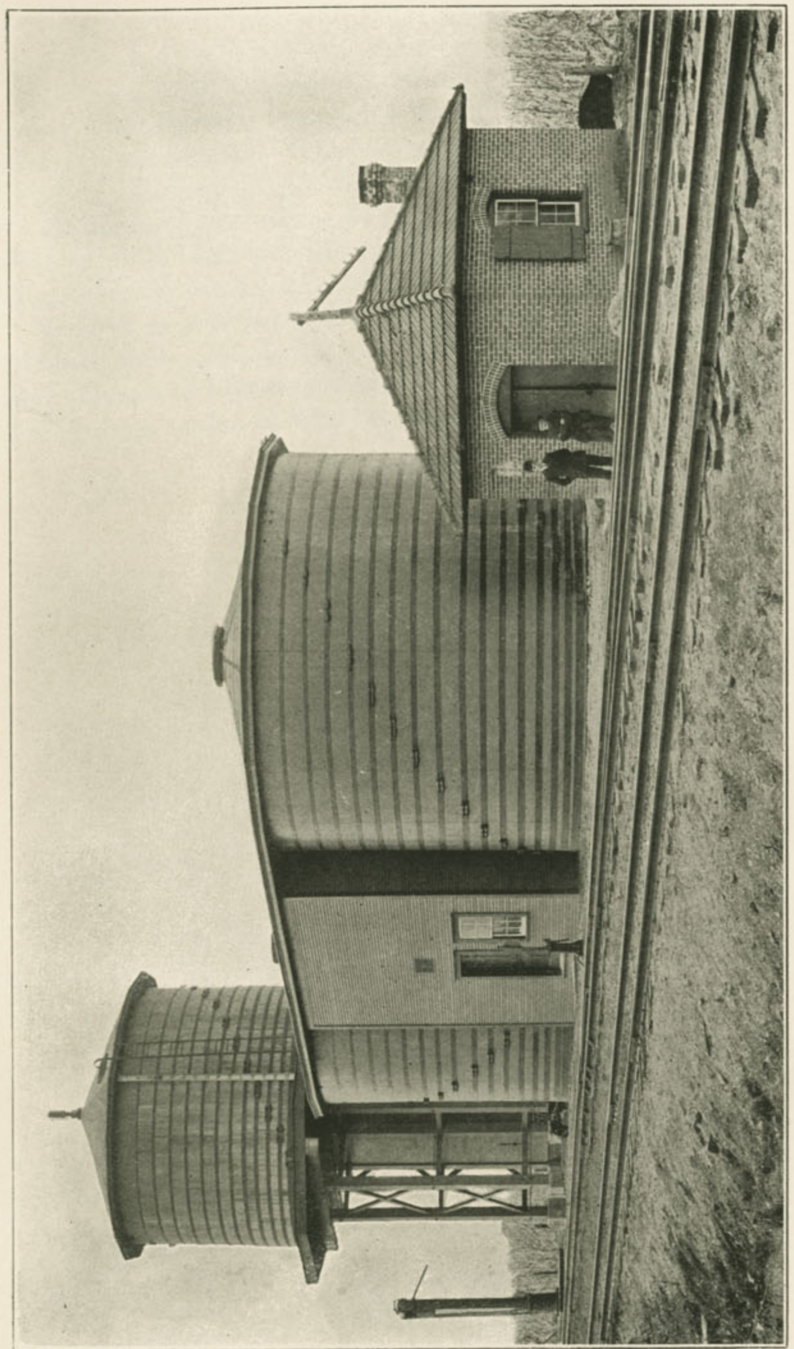
$$H.P.=\frac{S\times T}{33,000}$$

in which S=speed of train in feet per minute and T=total train resistance in pounds.

Suppose, for instance, the capacity of a tank is required for a locomotive which pulls a train weighing 300 tons a distance of 100 miles at an average speed of 60 miles an hour. From the above formula, it is found that the resistance per ton is 17 pounds. Since the train weighs 300 tons, the total resistance is equal to 5100 pounds. The speed being 60 miles per hour, or 5280 feet per minute, the horsepower is obtained by multiplying 5100 by 5280 and dividing the product by 33,000. The result of this calculation gives 816 horsepower. Allowing an efficiency of 75 per cent for the engine, the total horsepower of the engine will be equivalent to 1088 horsepower. Since each horsepower consumes 35 pounds of water per hour, the engine will consume 1088×35=38,080 pounds per hour. Since the trip will consume about two hours, the capacity of the tank must be at least 76,160 pounds. Since each gallon of water weighs 8.3 pounds, the number of gallons of water which the tender tank must hold is 9176 gallons. Any other set of conditions may be calculated in exactly the same manner.

As will be seen, this requires a considerable amount of water, so that on heavy runs of 60 miles or more it is usual to provide the road with track tanks, which allow the tender to take on water while the train is in motion. This is accomplished by means of a tank placed in the center of the track between the rails. This tank is made from four to six inches deep, and its average length is about one-quarter of a mile. It is always located on a level and straight stretch of track. When the tender is over the tank, water is taken up by means of a scoop, the inertia of the train forcing the water up into the tank. As soon as the tender is over the track tank, the scoop is lowered, and when the tank is filled, or when the train approaches the end of the tank, the scoop is raised by the fireman. This is done by means of a lever shown in Fig. 1. The amount of water delivered to the tender varies with the speed of the train. It is usual on high speed trains to slow down to at least 40 miles per hour, at which speed it is possible to take on water without injury to the apparatus.

Tenders are also equipped with tool boxes, in which may be kept small tools, signals, etc. The coal is held in position by means of gates or boards, which may be dropped into grooves in the side of the tender as occasion requires.



WATER-SOFTENING INSTALLATION ON THE CHICAGO & EASTERN ILLINOIS R. R., LOCATED AT DICKINSON, INDIANA. CAPACITY, 20,000 GALLONS PER HOUR. WATER IS SUPPLIED BY GASOLINE ENGINES, WHICH ALSO OPERATE THE STIRRING DEVICES

(Wm. B. Scaife & Sons Co.)

Corrosion and Incrustation

Ordinary water is not simply a compound of two parts of hydrogen to one of oxygen, but in its natural state it always contains a great many other things than these two gases. Sometimes it contains free nitric and sulphuric acids. River water, as a rule, is heavily loaded with vegetable and organic matter, and nearly all lake waters contain limestone. Artesian and spring waters often contain soda as well as other foreign matter. These mineral substances are dissolvel by the water in passing through the soil. A complete list of the common impurities is given below.

Weight of Impurities in Water. The weight of the impurities in water varies greatly, but in moderately good water it is often from 20 to 50 grains per gallon. As an illustration of the kind and amount of impurities found in boiler feed waters the following analysis may be taken as a fair sample:

Silica	.105	grains per gallon
Oxide of Iron and Alumina	.362	" " "
Carbonate of Magnesia	13.794	" " "
Carbonate of Lime	11.491	" " "
Sodium and Potassium Sulphate	3.569	" " "
Sulphate of Lime	Trace	" "
Sodium and Potassium Chlorides	3.300	Grains " "
Total Solids	32.621	" " "

The total solid matter amounts to 4.75 pounds per 1,000 gallons. A U. S. wine gallon of 231 cubic inches is standard. A grain is one-seven-thousandth of a pound, hence a locomotive steam boiler, evaporating 600 gallons of the above-mentioned water per hour (about 160 horse power) would collect a deposit calculated as follows:

$$\frac{600 \text{ (gals.)} \times 4.75 \text{ (lbs.)}}{1000 \text{ (gals.)}} = 2.85 \text{ pounds.}$$

This is the approximate amount of impurities collected in one hour. Part of this would form sludge and the remainder would be converted into hard scale. If this boiler were worked a week of 60 hours, there would collect $60 \times 2.85 = 171$ pounds of solid matter. In less than three months this would amount to more than one ton. The following table shows the principal impurities to be found in waters, some of them being in all waters, and all of them in some waters. In the usual order of their importance, together with their effect, they are:

IMPURITIES.	CAUSING
Sulphate and Bi-carbonate of Lime (most common of all)	Hard incrustation.
Sulphate, Chloride and Bi-carbonate of Magnesia	Incrustation and possible corrosion.
Chloride of Sodium and Carbonate of Soda	Priming, foaming, and incrustation.
Bi-carbonate and Peroxide of Iron	Incrustation and corrosion.
Dissolved Carbonic Acid and Oxygen	Corrosion.
Sediment, Mud, Clay, etc.	Incrustation.
Organic Matter, Sewage, etc.	Priming, scale or corrosion.
Grease	Corrosion.
Nitric and Sulphuric Acids	Corrosion.

Scale. By scale is meant an incrustation on the inside of the boiler on the submerged or water-covered surfaces. This scale is hard as rock and formed of lime, chalk and iron. These solids are actually a part of the original water, and cannot be detected by the eye, yet they are always left behind by the steam, and rapidly accumulate unless some means are taken to get rid of them. This point can be made evident to anyone who will take half a glass of ordinary clear water and place a teaspoonful of salt in it. After stirring for a few minutes, the salt will entirely disappear and the water will be as clear as before. It is in this way that nearly all solid matters are contained in feed waters. It is this condition that exists when solid matter is said to be in solution. If the water in the glass is allowed to evaporate, the salt is left behind. In the same way the solid matter is left in the boiler when steam is formed. Sometimes impurities exist in water, but are not in solution. In this case they are held in suspension. This occurs in common muddy water, which is simply clear water discolored by particles of dirt floating around in it.

Evil Effects of Impure Feed-water. The evil effects of impure feed-water may be explained under three principal heads: (1) Loss of Fuel; (2) Loss of Power; and (3) Danger. These conditions would exist in the average locomotive if no means were taken to purify the water or to prevent the scale from forming. The troubles and their causes are fairly well understood, and the proper method of treatment is described further along in this section.

Loss of Efficiency Caused by Scale. Both scale and sediment are poor conductors of heat, compared with iron, and their presence in a steam boiler will materially increase fuel consumption in the generation of steam. The loss of fuel caused by a coating of scale on the heating surface of a steam boiler varies considerably because it depends on the composition of the scale; some being much more heat-resisting than others. Some scales resist heat one hundred times as much as a boiler plate of the same thickness. A layer of scale as thick as $\frac{1}{4}$ inch often causes a loss of 35 per cent of fuel; while, if it piles up as thick as $\frac{1}{2}$ inch, it may cause a loss of over 60 per cent.

Not only is there a loss in fuel, but there is a diminution in the evaporative power due to scale. It has been estimated that there is a reduction of from 2 to 4 per cent a week in the quantity of water evaporated per pound of coal, when working with good water and coal, due to accumulation of scale. A boiler after working for four weeks would probably evaporate 8 to 16 per cent less water per pound of coal than when in a clean condition. Even coal-mining concerns, who reckon that fuel costs them nothing, take pains to remove the scale, as they want all the power their boilers can give them.

The waste of fuel and loss of power caused by a thick scale are so great that it is always expedient to incur the expense of purifying feed-water that contains much scale-forming matter. The statement that a little scale is good for the boiler is often heard, and this is trus when the feed-water is of a corrosive nature. The effect of corrosion is more insidious and injurious than scale, and it is consequently advantageous to permit the formation of scale of the thickness of an egg-shell as a preventive against corrosion.

Overheating Caused by Scale. With the loss of heat occasioned by the presence of scale arises the danger of overheating the boiler. The heating frequently causes burnt furnace plates

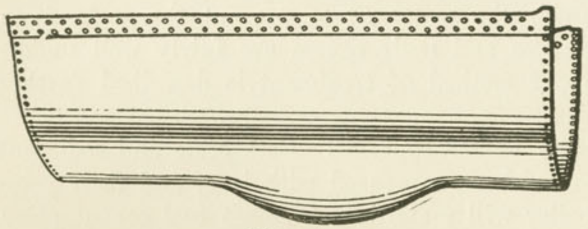


Fig. 1.

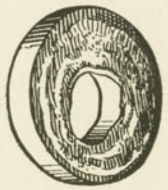


Fig. 2.

and bulged furnace crowns, as shown in Fig. 1. The heating increases the unequal expansion of the structure, which has a weakening effect, and frequently causes blistering or cracking of the boiler. The consequent wear and tear entails expense in loss of heat and time and in repairs.

In some instances the boilers are choked with scale and the circulation of water retarded. The tubs then become overheated

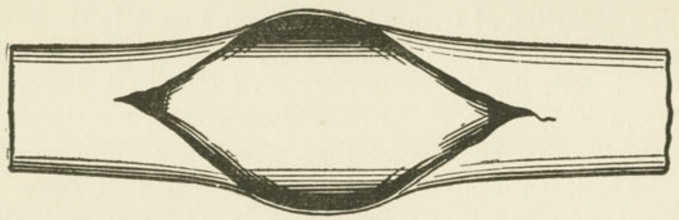


Fig. 3.

from lack of water, and ruptured, as shown in Figs. 2 and 3. Scale is thus a frequent contributing cause of boiler explosions. Again, the coat of scale may hide a dangerously corroded piece of plate or a defective rivet head, which would otherwise be discovered. Other impurities in water may be of a corrosive nature, and these are always dangerous.

Corrosion. By corrosion in steam boilers is meant the eating or washing away of the plates due to the chemical action of impure water. Gases absorbed by water, such as sulphurated hydrogen and carbonic acid, are very active in the corrosion of boiler plates. Grease and organic matter also promote corrosion. Even the purest waters, however, when containing air will cause this wasting. More or less air will be found in all waters, and this air escapes into the steam space when liberated by boiling. Air is heavier than steam, consequently it collects in bubbles, and if much is present it forms a layer between the water and steam and rapidly corrodes the plates in the vicinity of the water line. Care should be taken to prevent the feed-pumps drawing air.

Examples of corrosion are shown in Figs. 4 to 7. Corrosion is probably the most destructive of the various actions which tend to shorten the life of a boiler, and it may be classified

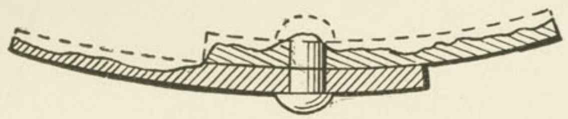


Fig. 4.

as (1) internal, and (2) external. Internal corrosion may be present as uniform wasting, pitting or grooving.

In cases of uniform corrosion large areas of plates are attacked and eaten away; there is no sharp division line between the sound boiler plate and the wasted part; and often the only way to detect it is by drilling a small hole through the suspected plate and measuring the thickness. An instance of this is shown in Fig. 4, the dotted line showing the outline of the plate when new.

Pitting. Pitting proceeds from the same cause as corrosion, but is the result of the chemical action becoming intensified and contracted at a particular part. This defect can readily be perceived by holes and cavities from $\frac{1}{32}$ inch to $\frac{1}{4}$ inch deep, as is shown in Fig. 5.

When the pitting is regular over an area of the plate, as though a charge of shot had been fired into it, it is known as honey-combing.

Grooving. Grooving or furrowing is due to the action of corrosion on a surface at a point at which expansion or alteration of shape is localized. Many boiler explosions have been caused by corrosive grooving. A shell thus weakened is shown in Fig 6. Corrosive grooving may take place in the end plates in the vicinity of anglehoops, as shown in Fig. 7. In the case of Fig. 6, the common lap joint is distorted slightly from the true cylindrical form, and the steam pressure tends to bend the

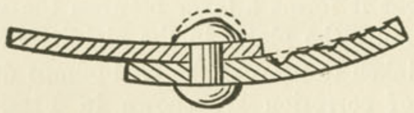


Fig. 6.

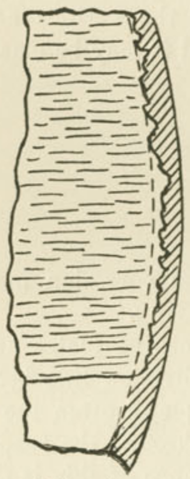


Fig. 5.

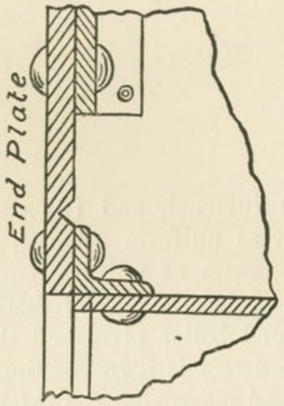


Fig. 7.

plates at the joint. This bending action is liable to start a small crack, which soon deepens into a groove when acted upon by the corrosive agents in the water. When a thick layer of scale occurs, unequal expansion is liable to crack it and expose a fresh surface to corrosive action, and thus grooving appears.

Prevention of Corrosion. To prevent corrosion all feed-water known to contain corrosive impurities should be avoided if possible. When bad water must be used, the impurities should be neutralized by adding alkaline substances, such as "soda."

In those vicinities, such as Pittsburg, where acids are commonly found in the waters, the water should be treated in some way. Refined mineral oil has been found effective in preventing corrosion in steam boilers using acid feed-water. Only the best refined mineral oil having a vaporizing point of at least 600° F should me used. By its use the interior becomes coated with a thin film of oil which protects it against corrosion. When this oil is used, a portion of the water should be blown off daily, and the boiler should be frequently examined to ascertain the effect of the oil. Painting with graphite has in some cases been effective in stopping corrosion.

Galvanic Action. There is no doubt but that a considerable amount of corrosion in boilers is due to galvanic action; that is, the generation of electricity. Whenever two different metals are placed in a solution capable of acting chemically on both of them, and are in metallic contact, a greater or less electrical current is set up, and one of the metals is rapidly attacked and wasted away. This is known as the positive, and in galvanic battery work iron is always positive in the presence of copper. The inactive plate is known as the negative. Iron is both positive and negative in the absence of other metals. In the presence of zinc, however, iron becomes negative. Zinc then is an effective protector from one form of corrosion. A small quantity is sufficient, a good proportion being a slab 12x6x½ inches to every 70 H. P. These slabs are usually attached to a stay, and should be removed at regular intervals. Galvanic action is not nearly so common as some people seem to think, and it is doubtful if the action on the zinc slabs is always electrical, yet, if the corrosion of the boiler plates is lessened, their use should be continued even though the action is not fully understood.

Grooving can be prevented to a certain extent by the above remedies for corrosion. In addition, the excessive strains caused by expansion, and so often giving rise to grooving, can be reduced by more careful firing. Also those joints liable to cause a buckling action should be avoided in the design. Any abrupt change in the temperature of the shell, such as might be caused by delivering cold feed-water on hot plates, emptying the boiler while hot, etc., is almost sure to cause leakage at the seams.

Corrosion Affected by Character of Boiler Material. Another factor having an important bearing on the wasting away of boiler plates is the material of which they are made. It is a fact of observation that corrosion sometimes takes place on the tubes, sometimes on the bottom surfaces, and occasionally it will be localized in a few spots. Generally, the action is very irregular, and without doubt is frequently due to the character of the metal. The metal should be homogeneous in composition and texture, should be well worked, thus making it fibrous rather than crystalline, and all scale and dirt should be removed from the surface.

INCRUSTATION.

In nearly every section of the country the water has a different class of impurities, but the most common are the limes and magnesia. These substances are the principal cause of incrustation (hard scale formation) in boilers. Carbonate of lime (marble) and magnesia are almost insoluble in pure water, but dissolve readily in water containing carbonic acid gas. This gas is driven off by boiling, and the lime and magnesia, before held in solution, are now thrown down in the solid form as insoluble deposits. A part of this mineral matter is deposited in the form of a fine powder, which forms mud or sludge, and the remainder settles on the plates of the boiler as hard scale.

The impurities are not all set free from the water at the same temperature. Thus the carbonates of lime are precipitated at a temperature of from 180° to 250° Fahrenheit, while the sulphates of lime are not released until a temperature of from 300° to 400°, corresponding to about 150 pounds pressure, is reached.

The small solid particles, when set free, remain for a time suspended in the water, being carried around by the circulation, but gradually they settle down on tubes, plates, and other internal surfaces. The lime matter then becomes scale, which soon bakes to the plates, and, if no means of prevention are used, a crust from 1-16 inch to ½ inch thick will soon be formed on the inner surface of the boiler. The great disadvantage and danger of such a condition have already been pointed out. Some impurities do not give rise to as troublesome a scale as others.

Prevention of Incrustation. All methods for preventing scale may be divided into two classes: (1) chemical, and (2) mechanical. Under chemical means, the method of precipitation by heat is included. Water will not hold some solids in solution when it is hot, 200° or more, and, consequently, these impurities precipitate out usually as a whitish or grayish mud. With higher temperatures, considerably more impurities can be removed, principally the sulphate of lime. This chemical compound is known as plaster of Paris, and is precipitated at a temperature of 300° F.

Boiler Compounds. The necessity of purifying feed-water led to the introduction of innumerable chemical compounds, for the prevention or removal of scale from boilers. These "compounds" usually contain lime or soda, or a mixture of both; but caustic soda forms the basis of most compounds, and is the real efficient remedy in nearly all of them. Organic substances, such as sumac and oak bark, are used successfully in some cases, but they are not suitable for all kinds of water. The soluble constituents are dissolved by the water, and basic tannate of lime is formed, which separates as a loose deposit, and does not form scale. Waters vary so much in the kind and quality of their impurities that there is no universal specific for purification, and different waters require different treatment, a chemical examination being a necessary preliminary to remedial measures.

Carbonates of lime and sulphates of lime are so common, and cause so much trouble, that their treatment will be explained in more detail. The common foe of these impurities is soda. Under this name (soda) several substances are used as preventives of scale in steam boilers. The cheapest and most common is carbonate of soda ("soda-ash"), which comes as a white powder. When "soda-ash" is crystallized by dissolving in water, we have "sal-soda." This is commonly known as "washing soda," although this term, or "washing powder," is also applied to a form of "soda-ash." Caustic-soda is an opaque white, brittle solid made by heating carbonate of soda with slacked lime. A solution of caustic soda in water is known as soda lye. For ordinary cases, .40 pounds of soda-ash, .60 pounds of sal-soda, or .35 pounds of caustic soda, per 1,000 gallons of water will be sufficient to precipitate most of the scale-forming matter.

It is best to make a solution of the soda and feed to the boiler continuously. The impurities are sometimes removed by precipitating in large storage reservoirs, into which only cold water is fed. It takes longer time and more space than the hot water treatment, but is economical where land is cheap and large volumes of water must be handled, as along many of the Central and Western railroads.

The cost of treatment with soda is very low, only about one grain of soda-ash being required for each grain of sulphate. Thus, if there are seven grains of sulphate per gallon of water, it would require about one pound of soda-ash per thousand gallons. Six thousand gallons would supply 160 H. P. boiler a day of ten hours. The cost would then be less than ten cents per day. If there are any free acids present, they should also be neutralized by an additional amount of soda. An excess of soda will impair the steaming facilities, and will also have a corrosive effect on the iron. This is indicated by foaming, leaks, and the white salts of sodium oozing out through the joints, water gauges and other boiler connections. By means of chemicals, the water that has been treated can be tested, and the reaction shows at once whether the proper amount of soda is being used.

The soda can, of course, be fed directly to the boiler, and it will precipitate the scale-forming materials in the form of a powder or mud in a flocculent form, thus preventing the adhesion of the particles and the building up of scale. Gradually, however, there is a loose mud or sludge deposited, which is only a little less harmful than the scale.

Some waters already contain soda, and in one instance as much as ten grains per gallon of the carbonate were found. Of course, no further addition of the chemical is needed, and the treatment should be reversed; that is, carbonate of lime should be added.

Carbonate of magnesia is not so common as the lime salts, but when present can be dealt with in the same way.

Use of Zinc. Besides preventing corrosion, zinc has been used with success in some cases for preventing scale due to hard

waters. It causes the lime deposit to become pulverulent instead of forming into hard scale. Zinc does not prevent hard scale formation when organic matter is present. An incrustation composed of zinc oxide and other sediment is liable to form, which may cause overheating. If zinc is used at all, the boiler should be frequently examined, and its effects noted.

Use of Mineral Oils. Mineral oil rapidly dissolves scale, and is effective in preventing the formation of scale in some instances. Kerosene oil, used for this purpose, should be of the best refined quality, having a vaporizing point much higher than the temperature of the steam in the boiler. For ordinary cases a quart per day for 100 horse power is sufficient. It should, however, at first be used in smaller quantities, the effect carefully noted, and the quantity increased if necessary for obtaining the desired result. It should be fed little and often, or continuously, like a sight-feed lubricator. Although quite satisfactory in loosening up the scale, it is apt to cause leakage at the seams. Caution should be observed on entering a boiler in which kerosene has been used, as dangerous inflammable gases may be present.

Although this last treatment is included under "chemical methods," there is no chemical reaction whatsoever, the action of kerosene being purely mechanical, following the laws of capillary attraction. Kerosene, being light and volatile, penetrates everything of a porous nature, such as lime, magnesia, etc., thus softening the scale.

Surface Blow-off Apparatus. Many impurities are held in suspension and float as scum on the water for some time before settling. This fact has led to the use of the surface blow-off apparatus. Floating skimmers are placed in some boilers to collect continuously the floating impurities, and by piping conduct them to a receiving chamber outside the boiler, where the sediment separates out and the clear water returns to the boiler. This method is satisfactory, especially if there are many floating impurities, and also because it saves much of the heat that would be lost by blowing down. Foaming is sometimes caused by accumulation of grease, lime, and other foreign matter. The surface blow-off or skimmer is especially beneficial in these cases.

There are many districts throughout the country where the boiler waters in use contain impurities of a nature to cause foamings. Because of the small amount of hard scale-forming impurities, however, and the recurrence of the difficulty only at certain periods of the year, it sometimes becomes undesirable to treat the water in a purifying plant, or otherwise, and dependence is placed altogether upon frequent blowing down of the boiler and numerous washouts to overcome the trouble.

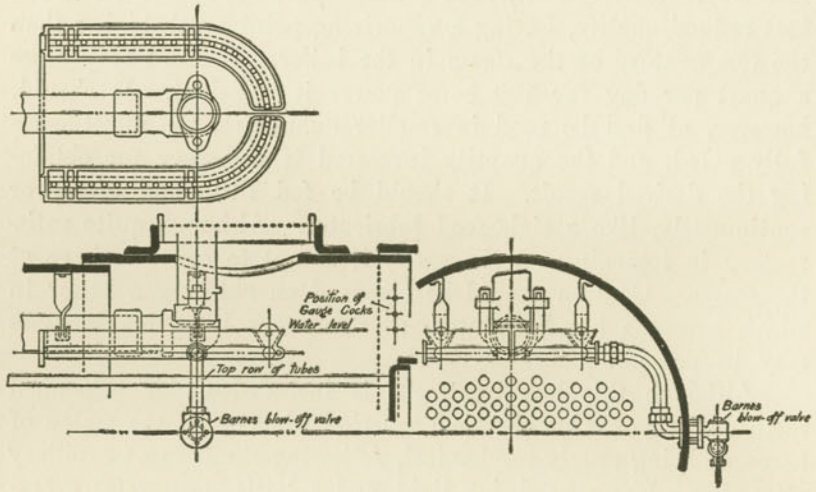


Fig. 8.

Barnes Boiler Skimmer.

Barnes Skimmer. For such conditions a skimmer and its connections have been designed by Mr. J. B. Barnes, superintendent of the locomotive and car departments of the Wabash Railroad, and successfully applied and used by him for several years. A 21x26 inch Atlantic type locomotive, which, before being fitted with this device, required a washout at the end of every 1,000 mile run, was easily able, after the application of the skimmer, to make a mileage of over 8,000 miles between washouts, resulting not only in a saving due to the cost of washing out and the water lost, but also in a much greater saving in connection with keeping the locomotive in service, this saving

being estimated at 50 hours saved between every washout when equipped with the skimmer.

The construction and application of the device is shown in Fig. 8. It consists of a short U-shaped trough, which includes in the same casting a 2 inch pipe below the trough with 5-16 inch cored holes between. This trough is located just above the average water level around the throttle pipe, and has a connection on

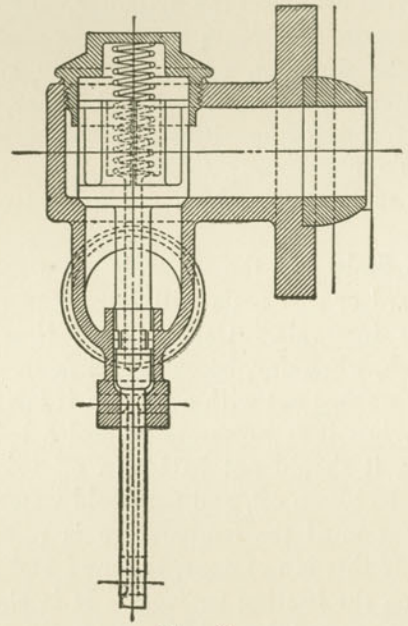


Fig. 9.
Barnes Blow-off Valve.

either side through 2 inch wrought iron pipes to especially designed blow-off valves, located outside of the boiler shell.

The blow-off valve, which is shown in Fig. 9, is made completely of brass with the exception of the spring, which is of German silver wire, and the lever, which is malleable iron or cast steel. The valve and its stem are cast integral, the part above the seat having four wings, which fit into a projection of the nut, forming a guide for the upper part, and the stem proper passing through the valve body, forming a lower guide, which insures the square and proper seating of the valve. It is operated by a lever from the cab, and the spring insures positive seating when the lever is released.

When the locomotive is working and starts to foam, there is a rush of water upward around the throttle pipe, and on such occasions the opening of the blow-off valve forms a counter circulation which draws the water away from the throttle and prevents it being carried over into the cylinders. From experiments which have been made, it appears that at the same time the impurities causing the foaming, which naturally arise to the top of the water, are carried away by this skimmer, a fairly large part of the scale-forming impurities are also blown off, and the boilers so fitted do not appear to be as badly scaled as other boilers using the same water which are washed out eight times as often.

Washing Out Scale. If the water is not treated for its impurities, either hard or soft scale will form, and it should be removed at regular intervals. Carbonate of lime forms a soft muddy scale, which, when dry, becomes like flour. This scale can be easily swept or washed out with a hose, if it has not been baked hard and fast. When it is necessary to cool a boiler for inspection and cleaning, it should not be blown off too quickly. The steam should first be blown off, and then cold water run in as fast as the hot runs out until the temperature is reduced to that of the atmosphere. If this is not done, the mud and scale are liable to become baked on the heating surfaces. It is also dangerous to blow off rapidly because of the sudden contraction, which is liable to break stays, etc.

The Advantage of Using Hot Water for Washing Out and Filling Boilers. There is a difference of opinion whether hot water will remove mud and slush from boilers more rapidly than cold water. However, the more general opinion among locomotive engineers is, that the hot water is more effective because it has a tendency to soften the mud and thereby remove it more rapidly. Washing the boiler with hot water before the boiler becomes cool removes the mud and slush before it has a chance to harden on the sheets, stay bolts and flues, while cold water has a tendency to harden the scale.

Where no facilities are provided for putting hot water in boilers, a number of railroads consider it good practice to admit cold water into the boiler as the hot water is running out, in order to bring about a gradual change of temperature on the metal. On other roads it is the practice to let out the hot water, remove the plugs and begin washing out immediately. This, however, is usually done on account of the limited time which the locomotive is at the terminal.

Where cold water is admitted to a boiler as the hot water is running out, for the purpose of cooling the water gradually, it seems to be very general practice to force the cold water through the injector. It is generally better to admit the cold water through the throttle, in order that the cold water may mix with the hot water at the highest point.

Washing boilers with cold water is often directly responsible for broken stay bolts and cracked sheets, especially when the cold water is allowed to cool the metal rapidly. When, however, sufficient time is taken to cool the boiler properly and no sudden changes of temperature are allowed to occur, washing with cold water may be done without ill effects to the sheets and stay bolts. When locomotive boilers are washed out with cold water, the great trouble seems to be that the round-house force does not allow the boiler to cool, which is responsible for the cracking of the sheets and stay bolts. Leaky tubes frequently occur after a boiler has been washed out with cold water, which is also especially noticeable when the process of washing and cooling has been pushed too rapidly. When cold water is used for washing and filling boilers, about 7 or 8 hours are usually consumed to blow off, wash out, fill up and raise steam to about 100 pounds pressure.

Hot Water Systems for Washing Boilers. That hot water systems for washing and filling boilers are of considerable advantage is indicated by the following roads, which have hot water systems located at their terminals: A. T. & S. F. Railway, at Albuquerque and Raton, N. M.; C. & O. Railway, at Clifton Forge, Va., Hinton, W. Va., and Russell, Ky.; C. B. & Q. Railway, at Grand Crossing, Wis.; C. I. & S. Railway, at Gibson, Ind.; C. L. S. & R. Railway, at South Chicago, Ill.; C. M. &

St. P. Railway, at Milwaukee, Wis.; C. R. I. & P. Railway, at Eldon, Ia., Blue Island and 47th St., Chicago, Ill.; C. C. C. & St. L. Railway, at Lyons and Mt. Carmel, Ill.; I. C. Railroad, at East St. Louis, Ill.; L. S. & M. S. Railway, at Elkhart, Ind., Toledo, Ashtabula, and Collinwood, Ohio; N. Y. C. & H. R. Railroad, at Albany, N. Y.; N. Y. N. H. & H. Railway, at South Boston, Mass.; P. & L. R. Railroad, at McKees Rocks, Pa.; S. P. Railway, at Oakland, Cal., and Wabash Railroad, at Montpelier, Ohio, Fort Wayne and Peru, Ind.

The advantages of washing out and filling boilers with hot water are, that it increases the life of the boiler and reduces the expense of maintenance, it shortens the time necessary to blow off a boiler, wash and re-fill, the terminal detention is considerably reduced, steam is generated in much less time and a smaller amount of coal is required for firing up.

The system for heating water to be used in washing and filling boilers which is used most widely embodies the principle of utilizing the heat contained in the water discharged from the boiler, to raise the temperature of the water to be used for washing and filling. Another method is to arrange the heating system so that all the water blown out of the boiler goes into a large tank, where the water is allowed to settle, and the water used over again. Arrangements must, of course, be made to dispose of the scale and sludge that settles in the bottom of the tank. Heating systems may also be arranged so that the heat of the steam released when the boiler is blown off may be used to heat the water for both filling and washing, or the boiler may be washed out with the water originally drawn from the boiler and the filling water alone heated by the steam blown off.

As regards the saving of time between the washing out with cold water and the washing out with hot, experience has shown that it takes 8 hours to wash out, fill and raise steam in a boiler filled with cold water, and practically only 3 to 4 hours when hot water is used, thus showing a saving of about 4 hours for each locomotive cleaned.

Removing Hard Scale. After hard scale has once formed, the most effective remedy is to remove it by hammering or chipping. If the inspection discloses incrustation, the boiler should be entered and the scale chipped off, or pulled off by hand. For this operation only an experienced man who understands the work should be employed, for there is great risk of injuring the boiler.

Before attempting to knock off the scale, it can be very much loosened by some chemicals. The action of kerosene has already been described. Caustic soda will greatly facilitate the removal of hard scale. By adding a quarter of a pound per horse power and steaming several hours just before cleaning, the scale will be rendered soft and loose.

The simplest method is to allow the boiler to cool as gradually as possible, and then stand full of cold water for a few days. The scale is then partially redissolved, and, on emptying the boiler, is removed with the water. The deposits should then be washed out with a hose. Time, of course, cannot always be had for such a treatment, and hence the quicker methods must be used.

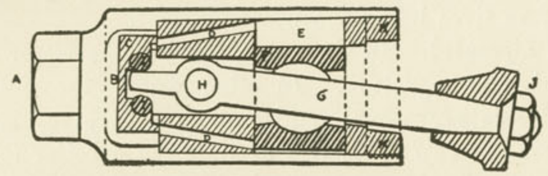


Fig. 10.

Mechanical Cleaners. There are several mechanical devices on the market for moving the hard scale from the tubes of fire-tube boilers. These devices are especially valuable since the tubes form the greater part of the heating surface, and they are the most difficult to reach and clean by ordinary means. The general principle of these cleaners is that of a small hammer made to knock rapidly against the sides of a tube. Uusually, compressed air or dry steam actuates the hammer. The action can be explained by reference to Fig. 10, which shows a sectional view of the Dean cleaner. The working fluid, compressed air or steam, is carried into the valve chamber B, and thence goes alternately through the ports DD into the piston chamber E. At a pressure of 40 to 80 pounds, the piston F moves the hammer handle G to and fro, imparting a vibrating motion to the hammer J. The handle of the hammer, being pivoted at H, works the valve C, so as to cover the ports in alternations. The hammer vibrates from 3,000 to 4,000 times a minute, and jars the scale loose. It has been found by careful experiment that the force of the blow is insufficient to harm the tube itself. The usual time for cleaning one tube is ten minutes.

BOILER EXPLOSIONS.

The life of a steam boiler depends upon three principal factors:

1. The design, materials, and workmanship.
2. The purity of its feed-water; and
3. The treatment it receives in service.

It frequently happens that the life of a boiler is ended by an explosion. The injury to and loss of the boiler itself are usually the smallest items of an explosion, the property loss and loss of human lives being the worst.

Power Liberated. In the average boiler the water and steam are at a high temperature. In other words, the heat confined in the boiler is very great, and heat is a form of energy. In general there are two cubic feet of water in a boiler to one cubic foot of steam. Let us suppose the pressure is 100 pounds per square inch. Then the water is at 337° F. One cubic foot of steam weighs approximately a quarter of a pound, and two cubic feet of water weigh 120 pounds. If the pressure on this water is reduced to that of the atmosphere, its temperature falls to 212° F. (337-212) B.T.U. are devoted to vaporizing the water.

The 120 pounds of water would then produce $\frac{120\ (337\text{-}212)}{966}$ =15 pounds of steam.

If the shell ruptures at any point, it is liable to tear completely open and relieve the pressure, so that the energy due to the generation of the 15 pounds of steam adds itself to that due to the expansive force of the quarter pound of steam, and thereby a violent explosion is produced.

The weight of steam in a boiler is so small that the energy stored in the water very greatly exceeds that stored in the steam. In the above problem the energy in the water is nearly 60 times that in the steam.

The following formula gives approximately the energy stored in the water and liberated by the explosion:

$$\text{Energy in foot pounds} = \frac{(T - 212°)^2 \times 778 \times W}{1135 \times T}$$

where T = the temperature of the steam at the instant of the explosion. W = the weight of the water in the boiler in pounds.

Let us apply the formula to a plain tubular boiler 60 inches in diameter, 15 feet long, and containing 66 3-inch tubes. It will weigh about 9,500 pounds, and usually contains about the same weight of water. We will suppose 10,000 pounds of water in the boiler under a pressure of 100 pounds gage.

The temperature of the steam at 100 pounds is 337° F. W= 10,000 pounds. Therefore by the formula we have:

$$\text{Energy in foot pounds} = \frac{(337\text{-}212)^2 \times 778}{1135 \times 337} + 10{,}000 = 8{,}258$$

× 10,000=82,580,000 foot pounds.

The indicated H. P. released by the explosion then is

$$\frac{82{,}580{,}000}{33{,}000} = 2502$$

if expended during a minute. It would be 60 times this, or over 150,000 H. P., if the energy was all expended in one second.

If a weight of one pound is thrown one mile high, it requires an expenditure of energy of 5,280 foot pounds. The energy liberated, therefore, in this example would project the boiler, if it was unimpeded, to a height of

$$\frac{82{,}580{,}000\ \text{(foot pounds liberated by explosion}}{9500\ \text{(weight of boiler in pounds)} \times 5280} = 1.6\ \text{miles.}$$

It would start with an initial velocity of 720 feet per second.

Causes of Boiler Explosions. The causes from which explosions proceed are very numerous, but we may classify them as follows:

1. Weakness and defects in the design, material or construction.

2. Wasting from corrosion, wear, and tear.

3. Improper treatment and attention. It must be borne in mind that this classification is arbitrary, and that the explosion may be, and usually is, due to a combination of causes.

Defects. Plates have sometimes been stayed so rigidly as to interfere with their expansion, and as a result fractures occur. Or, again, strains produced on one part by excessive expansion of another part may be greater than the strength of the material. Unnecessary and dangerous fittings should not be used. A hand valve should never be placed between a safety valve and the boiler.

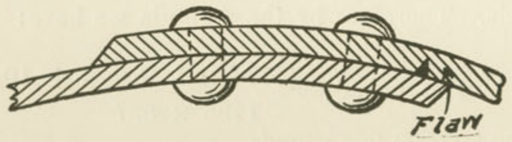


Fig. 11.

While all boiler material is carefully tested, and only accepted when conforming with standard specifications, yet it sometimes happens that defects will exist in the material which will be a source of weakness. Hidden flaws have been the cause of numerous explosions. Flaws along the line of rivet holes or between the rivet holes have frequently been caused by punching. Grooving has often been induced by improper calking, which causes the skin of the plate to be cut through, and an indent to be made along the outside of the lap of the joint.

Flaws. Incipient flaws are sometimes started in the plates, especially those of a hard and brittle nature, during the process of manufacture, which may afterwards develop into a rupture from the strains thrown on the boiler when at work. Two of the most disastrous boiler explosions ever recorded were due to a hidden flaw inside the lap of the longitudinal seam, similar to that shown in Fig. 11.

Causes of Fractures. Fractures have been started in many cases by the rough treatment the ends of plates receive in imparting the required set to the joint. When plates are bent after the rivet holes are made, the lessened resistance of the plates at the rivet holes permits the plates to become set instead of bending uniformly to the curve, and plates have been injured by flogging the bent edges back to the required curve.

Laminated or unsound plates are liable to develop blisters, which often become dangerously weak, due to excessive heating. Improper use of the drift for the purpose of drawing the rivet holes fair has sometimes started fractures.

A calking tool of improper shape may start a fracture by cutting grooves in the plate, as shown in Fig. 12. If the edges of manholes are not strengthened by rings, fractures may be started by the strains from screwing up the covers. Failure of riveted

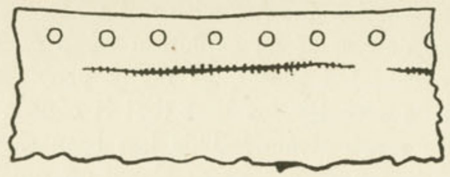


Fig. 12.

seams, due to fracture at the rivet-holes, has caused many explosions. These cracked rivet-holes are often due to the use of a too brittle plate, and sometimes to badly fitted rivets.

A chain is no stronger than the weakest link, so, too with a boiler which is dependent upon its numerous fittings. If any of these are defective, they are liable to fail and precipitate an explosion. Water gages are frequently of an inferior material that is seriously impaired by high temperature.

Wasting. Boilers are often prematurely worn out by corrosion, in some of the many ways explained under that heading. A boiler exploded due to wasting away of the plates, as shown in Fig. 4. Corrosive grooving has caused many explosions. In one case the boiler ruptured at a deeply furrowed longitudinal seam, and the rent spread around the boiler.

Improper Treatment. In the following few paragraphs attention is called to the dangerous results of mismanagement.

The mismanagement may be due to carelessness, incompetent help or lack of inspection. A fireman has certain duties to perform, and must attend to them at a certain time, otherwise he is taking more or less risk, and the responsibility of a possible explosion.

Many explosions are caused by overheated parts, due to defective circulation, shortness of water, and excessive incrustation. When the crowns of furnace tubes are overheated they are so much weakened that the tubes are liable to collapse and rupture under working conditions.

Muddy feed-water and even chemicals, if injudiciously used, may cause overheating. If a furnace tube is in danger of becoming overheated, the fire should be withdrawn. When, however, it is overheated, it is dangerous to disturb the fire. It is usual in such a case to smother the fire with wet ashes.

There is no danger of an explosion when cold feed-water is turned on to overheated plates, as many people think, because metal has so little capacity for heat that it cannot retain enough heat to generate much steam. This has been shown by experiments. In one instance, water was blown off until the crown of the furnace was exposed, and became red hot. Water was then pumped into the boiler, which caused the joints to leak badly, but no explosion took place.

Overpressure, and by this is meant a pressure above that adjudged safe, has caused numerous explosions. This may be due to a defective gauge or to a sticky safety valve.

PREVENTION OF EXPLOSIONS.

The best means of preventing explosions are: 1, Efficient periodical inspection; 2, Maintenance of boilers in good condition; and 3, Employment of trustworthy and competent attendants.

Inspection. The inspection should begin when the material is selected, and continue until the boiler is declared unfit for further service. In the manufacture especially the inspection should be thorough, impartial and vigilant. All the flaws described previously as defects of manufacture will be eliminated if the inspection is properly carried out.

While the boiler is in operation, an inspection should be made frequently. The inspection should be thorough, both internal and external. The inspector should rely upon the hammer test, as it has been shown by experience that this is the best method for finding flaws. He should sound successively each part, and when he strikes a defective place the difference in sound reveals it to his trained ear. A critical examination is then made to discover the nature and extent of the injury. If it be a lamination, the piece should be cut out and patched, or a new sheet put in; while if a check or crack is discovered it may be prevented from extending further by a plug or rivet judiciously placed, The important point is to discover defects in time to prevent their extending and precipitating explosions.

Among the various defects which may be found in a boiler by inspection the following are the most important: internal grooving; internal corrosion; external corrosion; deposit of sediment; incrustation and scale; defective braces and stays; defective settings; furnaces out of shape; fractured plates; burned plates; blistered plates; defective rivets; defective heads; leakage around tubes; leakage at seams; water gauges defective; safty valves overloaded; safety valves defective; and pressure gauges defective.

Defects of workmanship and material are more likely to escape detection in boilers of the locomotive type where the insides cannot be examined thoroughly. The defects in workmanship usually found are carelessly punched or fractured rivet holes; burned or broken rivets; plates damaged in flanging, dishing, bending, welding, hammering and punching; defective welding of plates and stays; fractures in the end of the tubes and carelessly secured stays. Old plates are frequently seriously damaged by patching them with new plates when the rivets are moved and by the expansion and contraction of new plate, especially if it is near the fire. Careful inspection will, of course, indicate a majority of these defects, but defects of material cannot always be indicated by inspection. Brittleness and lack of ductibility cannot be discovered by ordinary inspection, but it is the duty of the manufacturer to make tests from specimen pieces of boiler material, so that they come up to the specifications of strength and ductibility required.

Maintenance. Efficient work, and by this we mean both economy and safety, cannot be obtained with any apparatus unless the proper care is given it. This is especially true of boilers. To feel reasonably secure, the watchword should be eternal vigilance. If impure feed-water is used, scale will form which should be cleaned out regularly before it is thick enough to cause trouble. Corrosion takes place, fittings get out of order, etc., and unless these are given immediate attention the consequences may be disastrous.

In spite of safety-valves, fusible plugs, and other devices to render the boiler safe from explosion, the human factor is still present, and unfortunately has been responsible for numerous explosions. A fireman should never take anything for granted. He should know that the safety-valve, the pressure gauge, and the water column are in good working condition. There are a great many details besides these that require his constant attention, and for this reason only a man who has been properly trained should be put in charge.

REVIEW QUESTIONS.

CORROSION AND INCRUSTATION..

1. Name five different impurities which may be found in boiler water.
2. Suppose a boiler feed-water contained 34 grains of solid matter per gallon, how many pounds of solid matter would the boiler collect for each 1,000 gallons evaporated per hour?
3. What do you understand by the term scale in a boiler?
4. What are the evil effects of impure feed water?
5. What is the difference between corrosion and incrustation?
6. Explain how waste of fuel and loss of power are caused by thick scale.
7. In what way is it dangerous to a boiler to allow it to become filled with thick scale?
8. What different forms of internal corrosion may be present in a boiler?
9. What is uniform corrosion and how does it act upon the boiler plates?
10. What is pitting and how does it differ from honeycombing?
11. What is grooving and how is it generally started?
12. What is galvanic action and what is supposed to be its cause?
13. How does the character of the boiler material affect the amount of corrosion which may take place?
14. Name two general methods in use for preventing incrustation.
15. What are boiler compounds and why are they used?
16. How does the Barnes skimmer work and why is it used?

17. Explain the advantages of using hot water for washing out and filling boilers.

18. Name several systems which may be used for heating the water which is used for filling and washing boilers.

19. How is hard scale generally removed from a boiler?

20. What are mechanical cleaners and how do they operate?

21. What are the three principal causes of boiler explosion?

22. Upon what does the life of a steam boiler depend?

23. How may boiler explosions be prevented?

24. How would you inspect a boiler to see whether it is in proper condition?

25. What should be the duties of a fireman as regards the keeping of a boiler in good condition?

TYPE OF KENNICOTT WATER SOFTENER USED ON THE SOUTHERN PACIFIC AND BIG FOUR RAILWAYS
(Kennicott Water Softener Co.)

Water Supply and Water Softening.

Water Tanks. Except when the locomotive is taking water on the fly, the locomotive tenders are filled along the road from large tanks or reservoirs. These are located at suitable places,

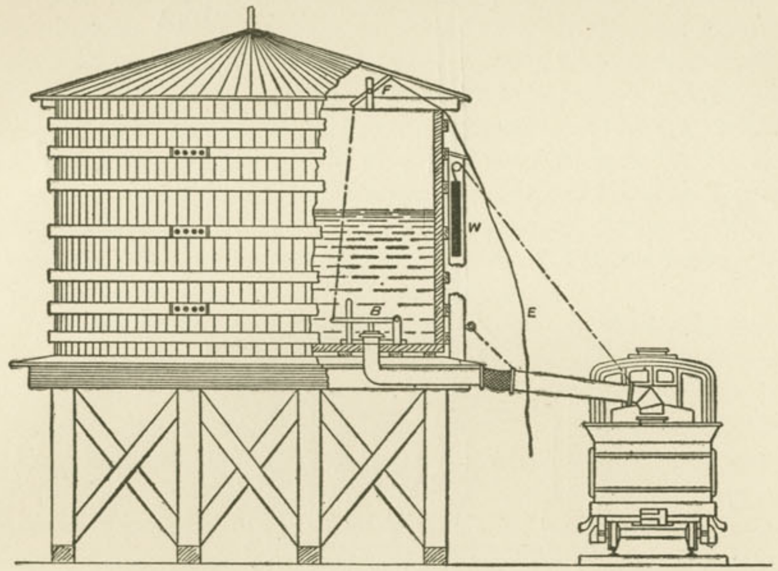


Fig. 1.

called water stations, along the line of the road. These tanks are filled either from natural streams, which are higher than the tank and flow into it, or else the water is pumped into them. The tanks are located usually near the track, as shown in Fig. 1, so that the water can be conducted by a spout, direct from the tank to the manhole of the tender. The water flowing from this spout is controlled by a valve, B, inside of the tank, which can be moved from the tender by a rope, E, which connects by means of the lever, F, to the valve, B. The spout is usually attached to the tank by a hinge joint, so that it can be lowered to the tender and then raised up out of the way of the engine and train.

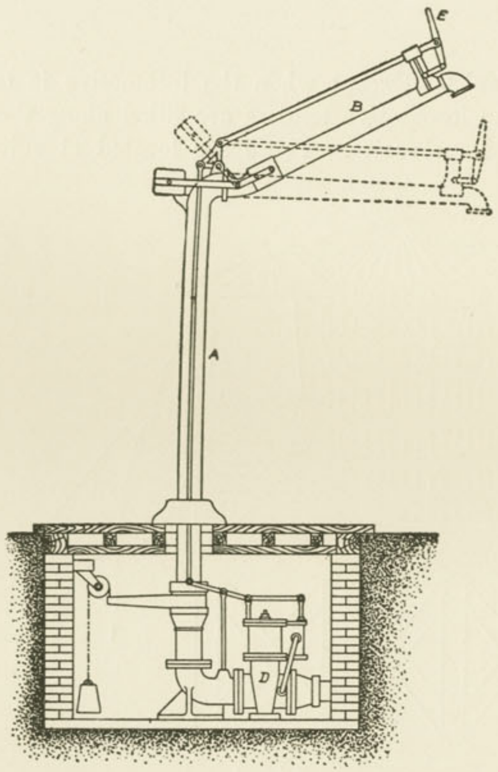


Fig. 2.

It is generally balanced by a counter-weight, W, suspended to one end of a rope, B, which passes over a pulley, and is fastened to the spout at the other end. The tanks are generally made of wooden staves supported on heavy frame work. When there is no room for the tank near the track, it may be placed in any convenient position at some distance from it, and the water may

be conveyed by an underground pipe to the place where the locomotive must take water. At the end of this pipe, a stand-pipe or water-crane may be erected. This arrangement is shown in Fig. 2, and consists of a vertical pipe, A, with a horizontal arm, B, which is made to swing over the manhole of the tender when the latter is to be filled with water. A valve, D, is also generally always attached to the pipe below ground, so that the water may be turned off and on by means of the lever, E, which is connected to the valve by means of rods.

Importance of Using Good Feed Water. It is of the utmost importance that a good supply of feed-water be used for locomotives. The use of impure water, or water which contains a considerable amount of mud, or which has lime or other mineral substance chemically combined with it, will very soon coat the inside of the boiler with a covering of scale, which makes the boiler very much less efficient, so that considerable heat is wasted in raising the steam. It is therefore very important that the very best source of supply be obtained; but, should it be impossible to obtain a good supply of feed-water, some chemical method of treating the feed-water should be used. This, in locomotive practice, is generally called "Water Softening."

Water, in its purest form, is a combination of two elements, hydrogen and oxygen, in the proportion of two parts of hydrogen to one part of oxygen. It is also one part by weight of hydrogen to eight parts of oxygen. Water which is used in locomotive boilers is seldom, however, in a condition of purity, as is evidenced by the large number of boilers in which scale or corrosion is found. The most desirable feed-water for a locomotive boiler is soft water, either that naturally soft, or water that has been treated by one of the many methods of water softening now in use, which destroys the scale forming properties.

Impurities Found in Boiler Waters. Among the impurities which are found in water may be mentioned: Calcium Sulphate, Calcium Carbonate, Magnesium Sulphate, Magnesia Carbonate, Magnesia Chloride, Sodium Sulphate, Sodium Carbonate, Sodium Chloride, Silica and acids.

Calcium Sulphate. Calcium sulphate is slightly soluble in water at temperatures between 284 and 302 degrees Fahrenheit, and beyond, being soluble in water free from carbonic acid gas at moderately low temperatures. It can be removed by means of carbonate of soda, commonly known as soda ash. Calcium sulphate in boiler waters causes hard incrustation, which is difficult to remove and causes an unnoticeable loss in evaporative efficiency of the boiler. It also becomes mixed with mud in the boiler and makes the scale quite hard. Water, which is only temporarily hard, will generally give a soft deposit of scale, the hardness in the water being due to calcium and magnesia carbonate. Water permanently hard, however, is usually due to calcium sulphate, which generally produces a hard scale, especially due to the fact that it becomes less soluble in water at the higher temperatures.

Calcium Carbonate. Calcium carbonate, which is commonly known as lime stone, marble or chalk, is readily soluble in water containing carbonic acid gas, and is more soluble in cold water than in hot water. Carbonate of lime is held in solution in water which contains carbonic acid gas, so that any chemical which will take up the carbonic acid gas will precipitate the calcium carbonate. The most frequently used chemical for this purpose is common building lime, or quick lime as it is called. It unites with the water and forms hydrate of lime, which takes up the carbonic acid and forms calcium carbonate, which, being then insoluble, is all precipitated as a white powder.

Magnesium Sulphate. Magnesium sulphate is very slightly soluble in cold water and easily soluble in warm water. It is a very common form of impurity in boiler feed water, and it decomposes at high temperatures forming scale. It does not of itself form scale, but when in a boiler containing carbonate of lime a chemical action takes place between the two, when hydrate magnesia and calcium sulphate are formed, both compounds making a very hard scale.

Magnesia Carbonate. Magnesia carbonate, or magnesia, as it is commonly called, is not soluble in water. Like carbonate of lime, it is held in solution by carbonic acid gas and is precipitated when the gas is driven off by the use of slacked lime. When sulphate of soda is present in boiler water, the frequent use of the blow-off cock will remove the concentrated solution and pre-

vent foaming, as it is quite soluble in cold water and less soluble in hot water.

Sodium Carbonate. Sodium carbonate, known as washing soda or soda ash, is soluble in hot water. It is used in large quantities where a cheap reagent is used, and must generally be used in conjunction with lime.

Sodium Chloride. Sodium chloride, or common salt, is always present in sea water, and is frequently found in artesian well waters when the wells are driven near the sea or ocean. It is soluble in water, which is generally increased by the presence of other salts in the water.

Silica. Silica is never dissolved in large quantities in steam boiler waters, but it is often combined with aluminium. When other impurities are present, it forms with them a jelly like paste, which can be detached from the boiler by scraping. Heat, however, will bake it into a hard crust, which must be removed by chipping. Silica is easily precipitated by boiling water at atmospheric pressure, and it is occasionally found in liberal proportion in low pressure boilers, the water of which contains sulphate of lime.

Testing Water for Impurities. In order to test water accurately for impurities a chemical test should be made, but there are many times where it is impossible to obtain a chemical analysis quickly, in which case the following rules may prove of value for finding the condition of feed water which is to be used for boilers.

To see whether the water is hard or soft, take a clean test tube and pour into it about three-quarters of an inch of soap solution, then pour into it three or four drops only of the water; if it becomes milky or curdy the water is hard.

To see if the water is alkali or soda, dip into a test tube half filled with water a strip of red litmus paper; if it does not turn blue, the water is not alkali. Now dip a strip of blue litmus paper into the water; if it does not turn red, the water is not acid.

To see if there is any carbonic acid present in the water, fill about three-quarters of an inch of water in a test tube and then pour in just as much lime water. If there is carbonic acid, the water will become milky, and on adding a little hydrate chloride acid the water will become clear again.

To test for sulphate of lime, fill the test tube to a depth of 1½ inches with the water and then add a little chloride of barium; if a white precipitate is formed, and it will not dissolve when you add a little nitric acid, sulphate of lime is present.

To test for magnesia, fill a test tube about one-fourth or one-third full of water and bring it to a boil, then add a little carbonate of ammonia and a very little phosphate of soda; if magnesia is present, it will form a white precipitate. The soap solution, which is used for testing for hardness, can be made by putting some fine scrapings of white soap into a bottle and pouring alcohol upon it, then cork the bottle and set it to one side, shaking it until it is all dissolved. Lime water can be prepared by slacking a small lump of freshly burned lime with half its weight of water, then take some of the slacked lime and put it in a bottle with some pure water, shaking it occasionally. The undissolved portion will fall to the bottom and the clear liquid, or lime water, being on the top, can be used for testing purposes.

Troubles Caused by Impure Water. Among the troubles which are due to impure water may be mentioned incrustation, corrosion and priming. Incrustation may be caused by sediment, mud, clay, soluble salts, bicarbonate of magnesia, lime or iron, organic matter, or sulphate of lime. When sediment, mud or clay and soluble salts are in the water, it may be pured by either filtering or blowing off. When bicarbonate of magnesia, lime, or iron is present in the water, it may be prevented by heating the feed water and precipitating it, or by treatment with caustic soda, lime and magnesia.

In case of organic matter, it may be precipitated either with alum or ferric chloride, and filtered.

Corrosion may be due to the presence of organic matter, grease, chloride or sulphate of magnesia, acids or electrolytic action. Organic matter may be eliminated as explained above. If grease is present, the water should be treated with slacked lime and carbonate of soda, and filtered. If chloride or sulphate of magnesia is present, the feed water should be treated with carbonate of soda, and if soda is present, some form of alkali should be used to neutralize its action. Should corrosion occur

from electrolytic action, zinc plates may be hung in the boiler to prevent it.

Should priming occur, due to organic matter, the impurities can be precipitated with alum or ferric-chloride, and the feed water filtered. If the priming is due to alkali in the water, the feed water should be heated and the impurities precipitated. If priming is caused by carbonate of soda in large quantities, barium chloride should be added to the feed water.

Railway Water-softening. The provision of a suitable water supply for railway service is a problem which requires the joint efforts of civil and chemical engineering in a good many parts of the country. At the recent convention of the American Railway Engineering and Maintenance of Way Association, the report of the Committee on Water Service related wholly to water softening, and an abstract of its more important sections are given in this article.

Types of Water Softeners. Two general types of softeners have been designed, the continuous and the intermittent. In the continuous type, the natural water is introduced into the softener, passing through one or more chambers and finally flowing off into the regular storage tank, the sludge being precipitated to the bottom of the softener and drawn off by means of a valve from time to time, as necessary. In the intermittent type the water passes into settling tanks, from whence it is drawn off by pumping or gravity, after reaction has taken place and the solids have been precipitated.

A modification of the intermittent type is used on some railroads by utilizing the regular storage tanks for settling purposes, but unless full time is given for reaction and settlement prior to the water being drawn off into locomotives, this form will not give the same economical results as either of the other forms. The control of reagents may be good, but a portion of the reaction will take place in the boiler, with a consequent increase in mud deposited.

Practical experience with the better-designed types of both the continuous and intermittent plants has shown that there is no difference in the efficiency of water-softening, providing the mechanical devices for control of the reagents are properly designed and the correct proportions given to the other parts of the plants.

Advantages of Intermittent System. The advantages claimed for the intermittent system are as follows: Simple and durable in construction; the absence of automatic reagent feeds; perfect mixing of reagents with water; reaction with one reagent completed before the second reaction starts, thus making treatment easier to adjust; it can be operated by the engineer or his assistant without interfering with the regular work; a constant quantity of raw water is collected to treat with a uniform quantity of reagent; the water can be treated with perfect uniformity, no matter how variable may be its character; the simplicity of the apparatus enables an unskilled workman to obtain as good results from it as an expert chemist; the rate at which water is drawn from the system does not affect results; the sludge collected in the settling tanks relieves the filter-bed, so that the filter can be run from five to six times as long without cleaning as would be the case were the sludge intercepted by it; the least waste of water in discharging sludge due to removing sludge only occasionally; the water can stand long enough to complete reaction, then settle as clear as it is possible for any water to settle; perfect clarification by means of mechanical filtration, without the use of a coagulant; filter-bed need not be renewed, as it consists of crushed quartz; the operation of this apparatus is the same as the method followed by the chemist in the laboratory, but on a larger scale with minor modifications; the use of two or more settling tanks makes possible an accurate daily record of the amount of water evaporated in the boilers, which feature will be appreciated by careful managers of large plants, who wish to keep a close check on fuel consumption; can be fitted into any available space; can be operated from the ground or top as may be desired.

Advantages of Continuous System. The advantages of the continuous system are as follows: Simple and durable in construction; automatic operation; perfect mixing of reagents with water; reaction with one reagent completed before the second reaction starts, thus making the treatment easier to adjust; it can be operated by the engineer or his assistant without interfering with regular work; accuracy in proportioning reagents to flow of water; ease in

adjusting quantity of reagents to variable quality of water; ample time for settling; final clarification by mechanical filtration; water need be supplied only at the rate used; perfect clarification by mechanical filtration; perfect filtration without the use of a coagulant; filter bed need not be renewed, as it consists of crushed quartz; large capacity in small space; can be fitted in any available space; can be operated from the ground or top as may be desired; will treat either hot or cold water.

Time Required for Precipitation. Practice has demonstrated that between three and four hours is necessary for reaction and precipitation, depending largely on the temperature of the water and the composition of the scaling matter held in solution. Water taken from running streams in winter should have at least four hours' time. In all softeners there should be some form of filter for water to pass through before finally passing into the storage tank, in order to eliminate any flakes of scale or mud forming matter that still may be held in suspension.

At least three feet of the bottom of each settling tank should be reserved for the accumulation of the precipitates; therefore, in estimating the settling space needed and the capacity of settling tanks, the settling space should be considered as lying entirely above this reserved portion.

Capacities of Settling Tanks. The proper capacities for settling tanks, measured above the space reserved for sludge, can be determined as follows: A=capacity of softener in gallons per hour; B=hours required for reaction and precipitation; C= number of settling tanks (never less than two); x=the number of hours required to fill the portion of settling tank above the sludge portion; y=number of hours required to transfer treated water from one settling tank to the storage tank (y should never be greater than x).

Where one pump alternates between filling and emptying settling tanks, the time for filling and emptying the total number of tanks less one must equal the time for reaction and precipitation in that one, and x would equal y. As the capacity of the pump must be double the capacity of treating plant, the settling capacity in each tank would be $2Ax = AB \div (C-1)$.

For plants where the quantity of water supplied to the softener and the capacity of the plant are equal, the settling capacity of each tank is equal to Ax. The total number of hours required to fill all the settling tanks should equal the number of hours required to fill, precipitate and empty one tank, as expressed by the following equation; $Ax=x+B+y$.

If $y=x$, $Ax=AB\div(C-2)$.

If $y=\frac{1}{2}x$, $Ax=AB\div(C-1.5)$.

Amount of Compound Required. Before considering the economical value of water-softening, it will be necessary to consider the reagents used and the quantity of reagents needed. Table 1 gives the quantity of reagents needed to remove one pound of incrusting or corroding matter from the water, also the effect on foaming quality of the water.

TABLE 1.—QUANTITY OF PURE REAGENTS REQUIRED TO REMOVE ONE POUND OF INCRUSTING OR CORROSIVE MATTER FROM THE WATER.

Incrusting or Corrosive Substance Held in Solution.	Amount of Reagent. (Pure.)	Foaming Matter Increased.
Sulphuric acid	0.57 lb. lime plus 1.08 lbs. soda ash	1.45 lbs.
Free carbonic acid	1.27 lbs. lime	None
Calcium carbonate	0.56 lb. lime	None
Calcium sulphate	0.78 lb. soda ash	1.04 lbs.
Calcium chloride	0.96 lb. soda ash	1.05 lbs.
Calcium nitrate	0.65 lb. soda ash	1.04 lbs.
Magnesium carbonate	1.33 lbs. lime	None
Magnesium sulphate	0.47 lb. lime plus 0.88 lb. soda ash	1.18 lbs.
Magnesium chloride	0.59 lb. lime plus 1.11 lbs. soda ash	1.22 lbs.
Magnesium nitrate	0.38 lb. lime plus 0.72 lb. soda ash	1.15 lbs.
Calcium carbonate	1.71 lbs. barium hydrate	None
Magnesium carbonate	4.05 lbs. barium hydrate	None
Magnesium sulphate	1.42 lbs. barium hydrate	None
*Calcium sulphate	1.26 lbs. barium hydrate	None

* In precipitating the calcium sulphate, there would also be precipitated 0.74 lb. of calcium carbonate or 0.31 lb. of magnesium carbonate, the 1.26 lbs. of barium hydrate performing the work of 0.41 lb. of lime and 0.78 lb. of soda ash, or for reacting on either magnesium or calcium sulphate, 1 lb. of barium hydrate performs the work of 0.33 lb. of lime plus 0.62 lb. of soda ash, and the lime treatment can be correspondingly reduced.

The first portion of the table considers the use of lime and soda ash as reagents, these being the cheapest, and, at the present time, the most common in use. The great objection to the use of soda ash is the increase in the foaming tendency of the water. The latter portion of the table gives the quantity of barium hydrate required to treat the carbonates and sulphates of lime and magnesia. The foaming tendency of water is not increased by the barium hydrate treatment, hence its advantage over soda ash as a reagent.

Barium hydrate has no advantage over lime as a reagent to precipitate the carbonates of lime and magnesia, and should not be considered as a reagent for these substances except in connection with the treating of water containing calcium sulphate. If there were no carbonates of lime and magnesia in the water, the combination of the calcium sulphate with the barium hydrate would produce calcium hydrate and barium sulphate. Calcium hydrate is soluble in water at ordinary temperatures to an extent of about 95 grains per gallon; therefore, the water would still be hard. Barium carbonate is easily soluble, and would react on the calcium sulphate and precipitate the incrusting matter. Barium carbonate is, however, only very slightly soluble, but can be produced in a form that will react on the calcium sulphate, by the combination of the barium hydrate with either magnesium or calcium carbonates, producing barium carbonate as one of the results of reaction, and if this reaction be carried out in the presence of calcium sulphate, the barium carbonate is not precipitated, but reacts on the calcium sulphate before it can separate out of the solution. For each pound of calcium sulphate removed by such reaction there would be removed an amount of the calcium and magnesium carbonates which would have required 0.41 lb. of lime, and the lime treatment can be correspondingly reduced.

In calculating the quantity of reagents necessary where barium hydrate is used in place of soda ash, the full quantity of lime should be calculated for the calcium and magnesium carbonates, and from this should be deducted 0.33 lb. of lime for each pound of barium hydrate required on account of the calcium sulphate.

Knowing the analysis of a water, the pounds of incrusting or corrosive matter held in solution per 1,000 gallons can be obtained by dividing the grains per gallon of each substance by seven, or the parts per 100,000 by twelve.

The amount of incrusting solids going into boilers daily from any water station depends on the analysis of the water and the quantity of water used from that station; hence the minimum amount of scaling matter which will justify treatment cannot be stated in terms of analysis alone, but should be stated in terms of pounds of incrusting matter held in solution of a day's supply. Neither can the composition of this minimum of scaling matter be definitely stated, since it requires a greater amount of reagents and much more expensive ones to treat the sulphates of lime and magnesia than to treat the same quantity of carbonates. Besides the scale-forming solids, nearly all water contains more or less free carbonic acid. Sulphuric acid is also found in waters, particularly in streams adjacent to coal mines. While this does not form incrusting matter, very serious trouble from corrosion will result from a small amount of this acid. In treating waters, the acids can be neutralized, and the incrusting matter can be reduced to at least 5 grains per gallon in most cases.

Benefits of Water-softening. In estimating the benefits, due to the removal of incrusting solids prior to the introduction of the water into the boilers, it must be remembered that carbonates of lime and magnesia, without the presence of either the sulphates of lime or magnesia, do not form hard scale, but are precipitated in the boiler as soft scale and mud, which can be removed for the most part by washing out and blowing off. A very small portion of either of these sulphates, in combination with the carbonates, will cause a hard, troublesome scale and increase the expense of boiler maintenance. With clean boilers, less fuel will be necessary to evaporate a given amount of water. Authorities differ regarding the increased amount of fuel required for a given amount of scale, but a conservative estimate seems to be about 10 per cent increase for each 1-16 in. of scale.

Saving in Fuel. The full saving of fuel will not be made if the foaming solids of the water have been increased during softening, as more water will have to be evaporated. Where matter is held in suspension in water, priming or foaming begins at an earlier concentration of matter in solution than if no suspended matter be contained in the boiler. In actual practice it is found that with a concentration of about 100 grains of foaming solids per gallon in locomotive boilers, trouble from foaming will begin. In order to avoid this trouble, the boilers must be blown off and new water admitted to take the place of this wasted water.

Water containing 10 grains of foaming solids per gallon will have reached the critical concentration on the tenth filling of the boiler; therefore, to reduce to the original concentration, the water should be completely changed, *i. e.,* one-tenth, or 10 per cent, of the water taken in the boiler would be blown off and wasted. For 50 grains per gallon of foaming solids, 50 per cent

would be wasted, as after one boiler full had been evaporated, the water would have reached the critical point.

From this it can be seen that the grains per gallon of foaming solids practically represent the percentage of water that must be wasted by blowing off, as the concentration reaches the critical point. In practice, it would probably exceed this, as it would not be policy to blow off large amounts at one time when on the road, on account of the disadvantage of admitting large quantities of cold water to take its place.

If natural water containing 10 grains of foaming solids has this quantity raised to 20 grains by using soda ash as a reagent, there would be a minimum of 20 per cent water wasted to keep it below the critical point, while only 10 per cent. would be wasted if treated with barium hydrate. Therefore, the grains increase per gallon of sodium sulphate, caused by using soda ash as a reagent, represent the minimum percentage point, while only 10 per cent would be wasted if the water was not treated, or if barium hydrate was used as a reagent instead of soda ash. Therefore, the grains increase per gallon of sodium sulphate, caused by using soda ash as a reagent, represents the minimum percentage of water wasted in changing boiler waters over what would be wasted if the waters were not softened, or if barium hydrate were used as a reagent. The minimum waste would be represented by the total cost of pumping and treating this wasted water by soda ash, plus the cost of the fuel required to raise this water from the temperature of feed water to the temperature of the water in the boiler.

For an increase of one pound foaming matter per thousand gallons of feed water, it would be the total cost of pumping and treating 70 gal. of water, and the fuel for heating the same to temperature of boiler water. For any other increase per thousand gallons of water, the minimum cost would be directly proportional to this.

With the foregoing points in view, the following equation is given to show the point where the benefits derived from treating the water will just balance the cost of treating: X=number cwt. (100 lbs.) solids removed from water per annum. B=money value of benefits received from removing 100 lb. solids, comprising saving in boiler washing and repairs, saving in fuel and increased service received from locomotives, represented by the interest on the cost of the additional number of locomotives that would be required to perform the service rendered by locomotives using the soft water, if based on the performance prior to treating the water. C=cost per 100 lbs. of solids removed to operate the plant, comprising additional cost of labor, additional cost of fuel or power, cost of chemicals, cost of current repairs. D= cost of plant installed. I=interest per annum on D. L= estimated useful life of plant in years. R=estimated value of materials recovered from plant after L years. S=annual depreciation of plant, equivalent to a sum per year, which, if placed in a sinking fund at I rate of interest, would amount to D—R in L years.

The benefits would just balance the cost when $XB=XC+I+S$.

The number of pounds solids removed daily to make benefits just equal the cost would be $(I+S)\div[3.65\ (B-C)]$. If more than this amount of solids is removed the plant will be profitable to the company.

Values for B can only be fixed for each particular case, as some of the matter held in solution is much more injurious than the same weight of other matters. The mechanical department of each railway should be able to approximate the values, knowing the proportions of the injurious matter in the water.

As shown by table 1, for every pound of calcium or magnesium sulphates removed by the use of soda ash as a reagent, the foaming solids of water are increased 1.04 and 1.18 lbs., respectively.

Where there is already a considerable quantity of foaming matter in the water, or where there are large amounts of these scale-forming sulphates to be treated, this increase in tendency to foam may be very objectionable. Barium hydrate as a reagent does not increase the tendency to foam, hence its advantage over soda ash. In treating either calcium sulphate or magnesium sulphate, one pound of barium hydrate performs the work of 0.33 lb. of lime and 0.62 lb. of soda ash. As already explained, a portion of the carbonates of lime and magnesia will be precipitated in treating sulphate of lime, and the lime treatment correspondingly reduced. At the present time barium hydrate is a much more expensive reagent than soda ash, but owing to its superiority as a reagent, chemists are experimenting to devise practical methods of producing it at a cost that will not make it prohibitive. The amount that railroads can pay for this material above the cost of soda ash depends entirely on the value of keeping foaming solids down.

For any given water station the following equation would express relative equivalent values, for a given quantity of water: A=pounds calcium sulphate to be removed. B=pounds magnesium sulphate to be removed. V=cost per pound of lime. X=cost per pound of soda ash. Y=cost per pound of barium hydrate. Z=value to remove 1.04 A+1.18 B foaming solids from water.

Then the reagents required would be: For soda ash treatment: (0.78 A+0.88B) soda ash, and 0.47B lime. For barium treatment: (1.26 A+1.42 B) barium hydrate, less 0.41 A lime.

Expense of reagents and wasted water would be: For soda treatment: $X\ (0.78\ A+0.88\ B)+0.47\ BV+Z$. For barium treatment: $Y\ (1.26\ A+1.42\ B)-0.41\ AV$. Then for equivalent values: $Y\ (1.26\ A+1.42\ B)-0.41\ AV=X\ (0.78\ A+0.88\ B)+0.47\ BV+Z$.

Methods of Water Softening. Softened water is water which has been freed from the solution of lime and magnesia, iron and aluminum, which can produce scale or corrosion. Softening of water is accomplished by a chemical precipitation. To remove carbonate, lime is used. On adding lime, the carbonic acid unites with it, resulting in the formation of calcium carbonate. When carbonate of lime alone is present, for each grain per gallon of carbonate of lime found in the water, four ounces of pure caustic lime for every one thousand gallons of water will be required to precipitate the lime as a carbonate. When there is only the sulphate of lime present, for every grain of sulphate of lime per gallon found in the water, $1\frac{3}{4}$ ounces of pure soda ash are required for one thousand gallons of water treated. When carbonate and sulphate of lime are both present, caustic soda alone is all that is needed to precipitate both of the solutions.

Among the systems which are used for water softening plants may be mentioned the Kennicott System, We-Fu-Go System, Scaife System, the Breda System and the Bruun-Lowener System.

We-Fu-Go Softening Systems. There are two types of We-Fu-Go water softening systems used on railways in this country. The one having the largest use, however, being known as the intermittent system. This system is installed both with and without filters, depending upon the character of the water which is used, and depends upon whether the water is still clear after treatment or whether it requires filtration. The intermittent system consists essentially of two or more treating and settling tanks, equipped with mechanical stirring devices operated by power, a reagent or chemical mixing tank with mechanical stirring device, and jet or other pump for introducing reagents into treating tanks, and a filter when conditions require it.

The treating tanks are filled alternately with water; while a tank is filling, the reagents are introduced and thoroughly mixed with the water by means of the chemical stirring devices, consisting of a specially designed paddle, revolved by power from an available line shaft, an engine or a motor. The paddle not only mixes the reagents with the water, but at the same time stirs up from the bottom the lime sludge of preceding purification. This sludge floats in the water, hastens the chemical reaction, and causes the now finely divided precipitate to form large woolly flakes heavy enough to settle quickly as soon as the water stops moving. This paddle-stirring device is the simplest and most efficient that can be devised; with reasonable care it will not get out of order; it does not have to be cleaned to keep it in working condition; and it requires very little power.

After a tank is filled, the stirring device is stopped, and the water permitted to stand, in order to allow the precipitate to settle to the bottom of the tank. The softened water is taken out of the tank by means of a hinged floating outlet pipe, arranged to rise and fall with the level of the water, so that the water is always drawn from the top. The water at the top being the clearest, carries the least amount of floating sludge through the floating outlet pipe to the filter beds; therefore, the filters can be run

the longest possible time without being cleaned. The rate of flow to the filters is automatically controlled, so that they are supplied with water as fast as it is drawn from them. Either pressure or gravity filters may be used; but in some cases no filter is necessary, depending on the kind of water required and the purpose for which it is used. When pressure filters are used, the settling tanks may be placed on the ground; when gravity filters are used, the bottom of the settling tanks must set about four feet higher than the bottom of the filter.

While one tank is being filled, treated and settled, the other is supplying treated water; and by the time it is empty the first tank is ready for use. In this way a constant supply of accurately treated, soft, clear water is always on hand.

Pipe connections, through which to fill the tanks and to wash the sludge from the tanks, are placed in the bottom. The washing of the settling tanks needs to be done about once a week, or when the sludge becomes deep enough to interfere with the stirring. To do this, it is necessary only to open the valves to the sewer and start the stirring device to mix up the sludge, which is soft enough to flow through the pipe into any sewer.

Another We-Fu-Go system which has been used to some extent for softening the water for locomotive boiler use is known as the We-Fu-Go continuous system. This system consists of a tower tank containing separate lime reaction, soda reaction and settling compartments with mechanical stirring devices in the reaction compartments; tank for slaking lime and dissolving soda or other reagents; lime and soda solution tanks with mechanical stirring devices; pump of special design for introducing the solutions into the reaction compartments; electric or water motor or steam engine to furnish power for operating the mechanical stirring devices and solution pumps, and either mechanical gravity or pressure filters. With this system, under certain conditions where it is desirable to use a lime water instead of cream of lime, we use our patented lime saturator. This system is automatic and continuous in its operation. The treatment is automatically regulated to the quantity of water passing through. The speed of the pumps introducing the reagent solutions is governed by the volume of water entering the system.

The water enters the lower compartment of the tower tank where it is treated with the first reagent, then passes into the second compartment where it is treated with the second reagent. Both compartments being fitted with mechanical stirring devices, a thorough mixing of the reagents with the water is insured, while the sludge of previous purification assists the precipitation.

From the second reaction compartment, the water passes into the upper or settling compartment of the tower. From there it flows to the filters through a floating outlet pipe, which acts as a regulator for the water entering the system. The settling compartment can be made large enough to give storage of treated water.

Comparing the We-Fu-Go continuous system with the intermittent system, it may be said that in a continuous apparatus the reagents are introduced proportional to the flow of water, and adjustment must be made in the quantity of reagents introduced to meet every variation for change in the water. Also no matter how carefully or accurately designed a continuous apparatus may be, an error must necessarily be introduced when wide variations occur in the quantity of water handled.

In the intermittent system, where definite quantities of water are treated all the time and the exact quantities of reagents required are weighed out, it is possible to treat accurately any water, no matter how it may vary as to quality or how the quantity used may be changed. The intermittent system is, therefore, better under highly varying conditions, but there are conditions under which the continuous system will give equally good results. These systems are built in capacity varying from 400 gallons per hour to 60,000 gallons per hour, although the continuous system is made to handle as high as 150,000 gallons per hour.

American Water Softener System. Another water softener system which has had considerable use on railroads is known as the American Water Softener System, or the Bruun-Lowener System. In this apparatus the softening solution is pumped from the ground level through a small pipe to the chemical reservoir tank, which is situated at the top, any surplus solution being

returned to the chemical reservoir tank by means of a small pipe.

The crude water supplied at the ground floor operates a small motor without waste, rises to the measuring and mixing mechanism at the top of the settling tank, where a certain definite percentage of reagent is automatically added, then is delivered with a whirling motion to the downtake, precipitating and coagulating the scale-forming solids, impurities and matter in suspension.

The precipitate which does not settle in the passage down the downtake drops out during the very slow rising in the increased area of the uptake, leaving practically no work to be done by the filter. The clear purified water then flows by gravity to the storage tank.

The mechanism for mixing and handling the softening solution is situated at the ground level. In the upper tank fresh burned lime is slaked in sufficient amount for twelve hours' operation. After slaking, the valve is opened and the lime-milk drops into the lower tank through a screen that removes the foreign matter. Soda-ash in the proper amount is then added, and the whole solution thoroughly stirred and kept in constant motion by the agitator. The shafting operating the agitator also operates the pump. The pump, drawing the solution through a fine strainer, raises it to the chemical tank at the top of the tower. Any surplus is returned to this lower tank by overflow pipe. The power for running this mechanism is furnished by a water motor.

The water enters the motor, revolves it and then passes out through the pipe on opposite side and up into the oscillating receiver. Since the motor is of the direct and positive type and a free exhaust is unnecessary, there is no waste of water. With an effective water pressure of three pounds, sufficient power is furnished by the motor.

These solution tanks are made of such proportions as to contain from twelve to twenty-four hours' supply, from which it can be seen that the man in attendance needs to spend but fifteen to thirty minutes each day at the plant, after which the machine will automatically care for itself as long as there is any softening solution remaining.

The crude water flows through a large pipe into a chamber of the oscillating receiver. As this chamber is filled, the center of gravity moves till equilibrium is lost and the receiver tips, pouring its contents into the tank, and at the same time bringing the other chamber of the receiver beneath the orifice of the supply pipe.

Above the receiver is the semi-circular reservoir tank containing the softening solution, in the bottom of which is a valve through which the solution falls into the oscillating receiver.

This valve is operated at each oscillation of the receiver, delivering a definite, constant amount of solution at each oscillation. The lift of the valve is regulated for any required amount of softening solution. The oscillator is always operated by the same amount of water, and the valve, with the constant head of solution in tank, always feeds exactly the required amount of solution whether there is one or ten oscillations a minute. Fixed to the under side of the oscillating receiver is a paddle which acts to prevent too violent movement of the oscillating receiver and more thoroughly mixes the water with the softening solution.

The chemical tank has a stirring device to keep the chemicals in constant motion. This agitator is operated by means of the rod and rocker arm connected with the receiver.

The water, upon leaving the oscillating receiver, passes to the bottom of the small tank, under the division plate and into the compartments containing the pipe, thus preventing any pulsations in the main settling tank, and thoroughly mixing the softening solution with the water. The angle at which this pipe is set causes the water to shoot in such a manner that it is given a whirling motion in passing down through the cylindrical downtake, as shown in a previous illustration. This whirling motion causes the precipitated matters rapidly to coagulate and settle out, almost before the water starts on its final upward course, thus relieving the filter bed. If water is taken from two or more different sources, a different softening mixture and oscillator may be supplied for each in the same softener.

Pittsburgh Water Softener Systems. The Pittsburgh water softener systems are also made in two different types for softening

water for use in locomotives. In the intermittent softening system the raw water to be purified passes into one of two settling tanks. While this tank is being filled with water, the solution pump delivers a lime solution from the solution tank into this tank of

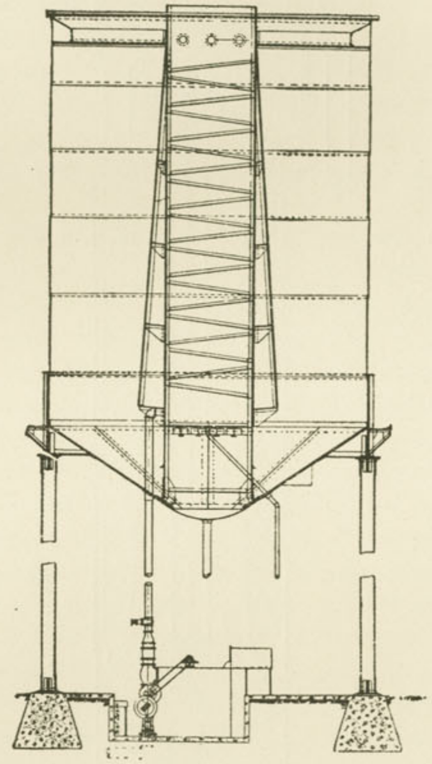


Fig. 3.

LONGITUDINAL SECTION OF PITTSBURG CONTINUOUS WATER SOFTENER SHOWING BAFFLE CHAMBER, MOTOR AND SOLUTION TANK.

water. When the water is within two feet of the top the soda ash is introduced in the same manner from another solution tank. When the chemicals have been added to the water, it is thoroughly agitated from the air receiver where a pressure of from 10 to 15 pounds of air is maintained with a compressor. Uniform agitation of the water in the tank is accomplished through the agitator rings for 15 minutes or longer and the water is allowed to settle for one hour or more, depending upon the quality of the water. It then passes out through a floating outlet spout into a filter from which it is piped into the clear water well or

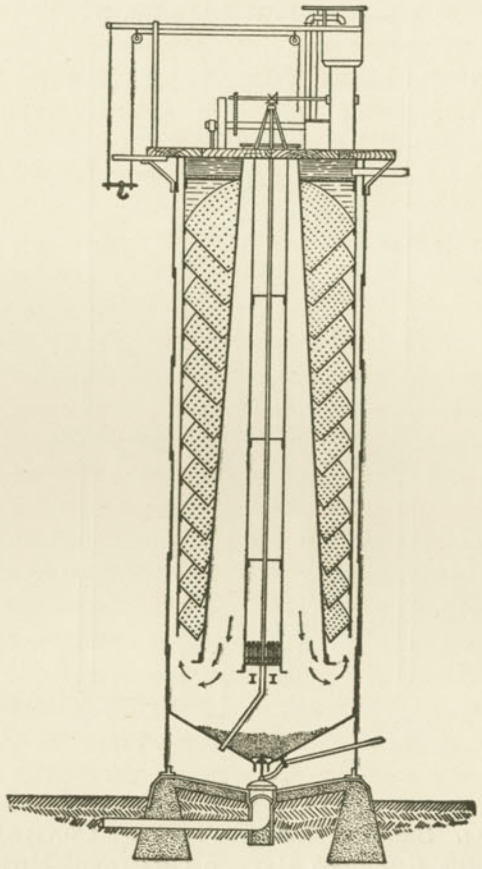


Fig. 4.

KENNICOTT INTERMITTENT WATER SOFTENER.

other point of delivery. When one tank is being emptied of the purified water the other is being prepared for use.

In the Pittsburgh continuous water softening system the varying quantities of water are treated automatically with varying quantities of materials proportional to the flow of water.

The water is pumped but once into the machine and is delivered at the bottom. After the impurities in the water to be treated have been precipitated from the water by chemical reagents, they are removed from the water as it passes through the apparatus, and the purified water overflows from the top of the softener by gravity into the storage tank. In this style of plant all of the operating parts are located upon the ground level, the chemicals being mixed and applied by positive automatic apparatus which may easily be cared for and examined at all times. A longitudinal section of this type of continuous water softener is shown in Fig. 3.

Kennicott Water Softener. The Kennicott system of water softening consists of automatically treating varying quantities of materials always in the same proportion, so that the water is softened continually and automatically. Fig. 4 shows one type, known as type A. It consists of a tall cylindrical tank with a platform at its top, on which is located the apparatus for dissolving the reagents and automatically varying their inlet to the raw water.

In the center of the tank is a conical downtake, within which is the lime-water saturator; the mixing-tank for this is in its top.

After reagents and raw water are thoroughly mixed, the scale-forming substances are deposited at the bottom, from which they are blown off or run off to sewer. After the water comes down the central tube it rises through the perforated baffle plates, upon which plates any remaining precipitate is gathered, after which it falls off to bottom. These plates never have to be cleaned. At the top the water finally passes through a wood-fibre filter, where any precipitate which has gotten through the baffle plates is taken up; the water then passes through the overflow outlet to the proper supply lines.

The power for mixing reagents and water is supplied by the water passing over a water-wheel in a casing, shown in the illustration. The lime and soda-ash are lifted by the same power; a drum on the water-wheel shaft, loose fit, is engaged by a clutch and operates a rope, also shown in the illustration.

The water flows from the "hard-water box" into the softener over the encased water-wheel; one or more of the reagent boxes are provided as needed.

As the amount of the water pumped into the softener varies the head of water in the hard-water box it raises or lowers the float in it. This float is connected to the lift-pipe, so that the head of the reagent over the opening in the lift-pipe is at all times the same as the head of hard water over opening in hard-water box.

One of the first water softeners installed upon the "Harriman Lines" was a Kennicott water softener which was put into operation at Point of Rocks, Wyoming, in 1900. This type has an external line dissolving tank supported upon brackets at the side of the main tank, and it is claimed that with the use of this softener, five tons of encrusting solids are removed each month which would otherwise be deposited in boilers of the locomotives drawing water at this point.

The removal of the encrusting solids from the water is accomplished by adding in correct and exact proportions by the machinery lime-water and a solution of soda-ash. The lime-water is made by putting a weighed quantity of lime in the small tank shown in the accompanying cut at the side of the main tank (in later forms inside of the main tank) and passing a stream of water, of a volume proportionate to the amount of hard water which is treated through the lime; the water dissolving the lime as it passes through it. This stream of water enters the lime dissolving tank at the bottom, and after passing through the lime continues to rise to the top of the lime dissolving tank and overflows into the top of the main tank, where it meets the stream of hard water from the artesian well. The soda-ash is dissolved in water in a small tank, or steel box, at the top of the softener and, by an automatic device, the solution of soda ash is added to the artesian water in the top of the main tank at the same point at which the lime water flows in from the lime dissolving tank. The process is continuous, the main tank being always full and the softened water overflowing into roadside tank at the side of the softener at the same rate at which the artesian water enters the softener. The softener is so arranged, and is of such size, that the settlings from the water after it is treated collect at the bottom, while the water reaches the overflow soft and clear. The settlings which collect at the bottom are blown off at certain times through a valve into a sewer. The power for operating the plant is derived from a water wheel at the top, driven by the water which is treated.

The capacity of this type is 8000 gallons per hour. The source of water supply is artesian well water, which has an average hardness before treatment of 21.19 grains per gallon, and after treatment the hardness is reduced to 4.51 grains per gallon. It is claimed that the cost of treating this water is one per cent per thousand gallons.

Another form of Kennicott water softener, which is known as type "B" is used on the Southern Pacific Railroad and the Cleveland, Cincinnati and St. Louis (Big Four) Railway, the capacity of the softeners used on the former road being 15,000 gallons per hour, while those used on the Big Four system have a capacity of 30,000 gallons per hour.

With the type "B" "Kennicott" the lime used in treating water is in the form of Milk of Lime. The water for treatment enters an oscillating receptacle, or tipping box, having two compartments and so attached to the shaft that when one compartment fills with water to a certain point, the weight of the water causes the oscillating receptacle to move downward around the shaft, allowing one compartment to empty, and at the same time bringing the other compartment into position to be filled. When the other compartment is filled with water to a certain point, reverse action takes place, allowing the other compartment to empty and bringing the one again into position to be filled. The oscillating receptacle being rigidly attached to the shaft, a rocking movement through an arc of about 90 degrees is given to the shaft by the movement of the oscillating receptacle. The movement of the shaft operates cups which feed the Milk of Lime from the box containing it into the water to be treated immediately after the water leaves the oscillating receptacle. Solutions of other chemicals used in treating waters are fed in the same way.

After the chemicals have been added to the water by the above described apparatus, it flows into the steel tank, the interior of which is so divided and arranged that the settlings from the water collect in the bottom of the tank and at certain times are drawn off into a sewer through a valve, while the water, softened and clarified, flows from the tank at a point near the top of the tank continuously at the same rate at which the hard water enters the chemical feeding apparatus.

Six water softeners of the type shown in Fig. 4 are used upon the Vandalia Railroad between Indianapolis and St. Louis. The capacity of each softener is 20,000 gallons per hour, the hardness of water before treatment averaging 21.00 grains per gallon and the hardness after treatment 2.63 grains per gallon. The six softeners cover a distance of 240 miles. One is installed at each of the three roundhouses of the road. The passenger locomotives are able to use treated water exclusively; freight locomotives must take some water at stations where there are no softeners.

Lime and soda ash are used to treat the water. Milk ot Lime and a solution of soda ash are made at intervals of twelve hours in the small house on the ground, and separately raised by means of a small pump to steel boxes in the house at the top of the softener, from which the soda ash solution is added automatically in exact proportion to the hard water which is to be treated. In the tank within the softener the Milk of Lime is dissolved, forming lime water, and by the same process the lime water is also automatically added in exact proportion to the hard water. The action of the softener is continuous so long as the hard water is allowed to enter the softener.

The Superintendent of Motive Power of this road in his report gives the following figures upon the results obtained from the installation of these softeners:—A reduction of 92.3 per cent in the number of trains given up; a saving of 80.5 per cent of time lost owing to engine failures; a reduction of 68.9 per cent in the number of delays; an increase of 39.4 per cent in the average mileage between repairs in classes 2 and 3; an increase of 10 per cent in the average mileage between repairs in classes 2, 3 and 4; a reduction of from 30 to 14 in the number of boiler-makers employed in the Terre Haute roundhouse; a decrease of 41 per cent in the cost of boiler repairs and an additional 4,000 miles per month more for each pool locomotive.

REVIEW QUESTIONS.

WATER SUPPLY AND WATER SOFTENING.

1. Describe two methods by means of which locomotive tenders are filled along the road.
2. What is the importance of using good feed water in locomotives?
3. What is the composition of pure water both by weight and by volume?
4. What is the most desirable feed water for a locomotive boiler?
5. Name six impurities likely to be found in boiler water.
6. What are the properties of calcium sulphate, and explain why it forms scale in the boiler?
7. What compound is most generally used to prevent the calcium carbonate in the water from forming scale?
8. When sulphate of soda is placed in a boiler how can it best be gotten rid of?
9. How would you test a water to find if it is hard or soft?
10. How would you test a water to see if it contained magnesia?
11. What are the principal troubles caused by impure water?
12. Suppose priming was caused by large quantities of carbonate of soda, what compound would you use to prevent it?
13. Name two types of water softeners in general use.
14. What are the advantages of the intermittent type of water softener?
15. Name some of the advantages of the continuous system of water softening.
16. What are the principal reasons why railroad systems are now using water softening so extensively?

17. How many pounds of lime would be required to soften water containing 100 pounds of calcium carbonate?

18. If a certain quantity of water used per day contains 50 pounds of calcium chloride, how many pounds of soda ash would you use to neutralize it?

19. Upon what does the amount of incrustating solids going into a boiler daily depend?

20. Why would you expect a saving in power when a locomotive uses softened water?

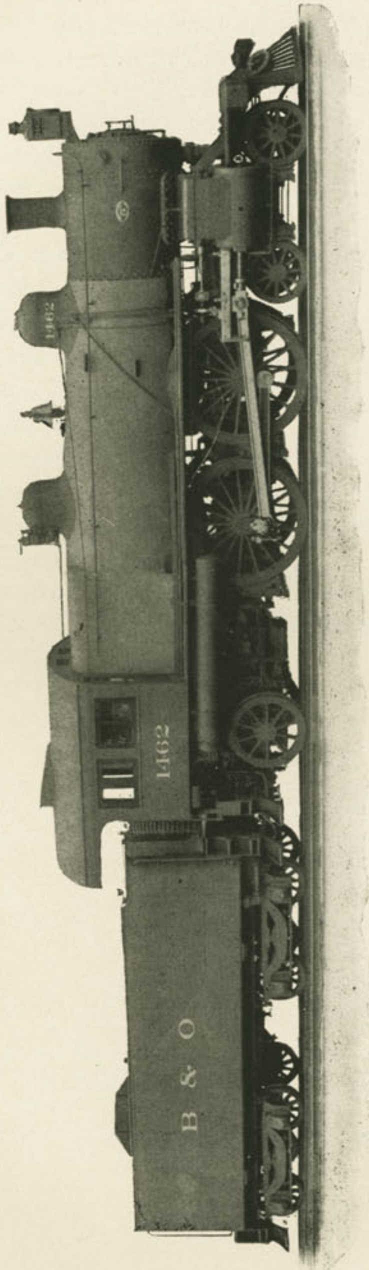
21. Describe briefly one general method of determining when water softening would pay for the chemical treatment.

22. Name four different types of water softening systems used on railroad systems.

23. Describe briefly the We-Fu-Go continuous system of water softening.

24. Describe briefly how water is softened in the American water softening system.

25. Describe how the water is treated in the water softener used on the Vandalia lines between Indianapolis and St. Louis.



ATLANTIC TYPE OF LOCOMOTIVE USED ON THE BALTIMORE & OHIO RAILROAD
(American Locomotive Company)

Feed Water Heaters

While the advantages of heating the feed water before it enters the boiler are well known, the numerous difficulties which are encountered in taking care of such an apparatus have always caused these devices to be looked upon with suspicion by railway men. In stationary engine practice, a saving of one per cent is effected for every ten degrees which the feed water is heated before it enters the boiler, so that it is no small wonder that in these days when economy of fuel is such an important consideration that steps are being taken to bring this important piece of apparatus to the practical attention of the locomotive designer.

Besides the economy due to heating the feed water, there is very much less strain on the boiler when warm water is admitted to it. It is well known that the enormous internal strains caused by the injection of comparatively cold water into a locomotive boiler are responsible for a large part of the difficulty that has been experienced in keeping the modern large-sized locomotive boilers from leaking. Experiments with devices for more thoroughly mixing the entering supply with the water already in the boiler have resulted in much improvement in this respect; but it is easily understood that to completely overcome trouble it would be simply a matter of heating the feed water to a temperature approximately that of the water already in the boiler, so that there will be but a slight difference in temperature when the water is admitted. It is also easy to understand that whatever heat is put into the feed water before it enters the boiler will not have to be provided later from the fire-box. This, of course, provided the heat is obtained from waste sources, results in either less coal required to furnish the same amount of steam, or a larger boiler capacity with the same amount of coal burned.

These advantages have been given more practical attention in those countries where the cost of fuel is very high, and where any device seeming to insure fuel economy has always been given more careful attention and thorough testing than in this country, and feed water heaters of various designs have been successfully fitted to a large number of foreign locomotives. One of the most successful of these was applied by Mr. Trevithick, locomotive superintendent of the Egyptian State Railways, and

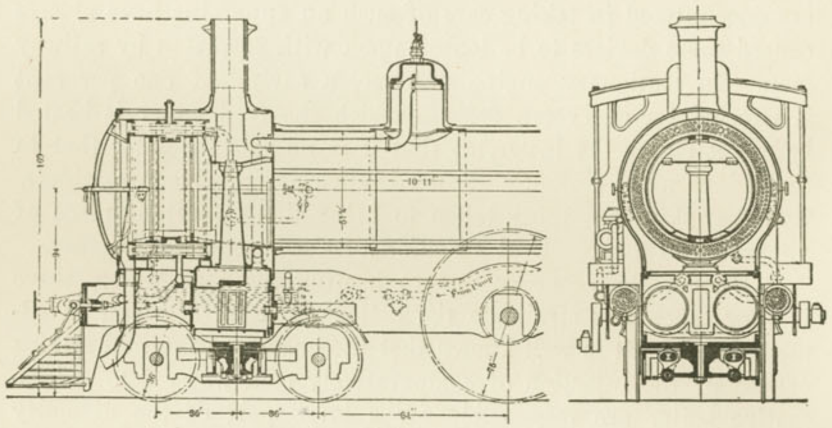


Fig. 1.

Trevithick Feed Water Heater.

an economy of approximately sixteen per cent is reported by the use of that heater.

Trevithick Feed Water Heater. The Trevithick feed water heater arrangement is shown in Fig. 1.

The feed water is drawn from the tender and forced into the boiler by means of a horizontal duplex pump located on the right side just ahead of the cab. This pump takes steam at boiler pressure and delivers its exhaust into the first section of the pump. The first heater is vertical, and contains nineteen five-eighth inch tubes, which are connected to headers at each end,

the upper header being connected to the exhaust pipe from the pump and the lower header having an opening to the atmosphere. The feed water circulates around the outside of the tubes.

On leaving the pump the water traverses in succession two other heaters, one on either side of the smoke-box. The one on the right is divided into two compartments by a partition, so that the water traverses twice the length of the heater in passing through. It then goes to the left heater, in which there is no dividing partition. These two heaters are heated by part of the exhaust steam from the cylinders. From these the water passes to the larger heater in the front end, which consists of an annular chamber containing 265 tubes one inch in diameter and eighteen inches long, arranged in three concentric rings and heated by the exhaust gases passing through the tubes. The total section of the heater tubes, which is but little larger than the section of the smokestack, is entirely utilized, and their position in reference to the fire tubes assures a perfect separation of the escape gases to the interior of all of them. From this heater the water passes to the boiler through the usual check valves.

Tests which have been made with this heater show that feed water at 68 degrees F. in the tender is heated up to 80 degrees in the first heater, raised to 159 degrees in the second heater, to 193 degrees in the third heater, and leaves the smoke-box heater at about 270 degrees F. The estimated saving in fuel is about sixteen per cent.

The Gaines Feed Water Heater. One of the first attempts to develop the capabilities of real feed water heating, under American conditions, is now being made by Mr. F. F. Gaines, superintendent of motive power of the Central Georgia Railway, who has recently received a Consolidation locomotive from the Baldwin Locomotive Works fitted with a heater of his design, which in principle follows that so successfully installed by Mr. Trevithick.

The constructional features of this heater are shown in Figs. 2 to 5. It consists of—first, a duplex, horizontal feed pump, which delivers the water to two heater drums secured beneath the running boards, one on either side, and connected in series. These drums are filled with small tubes, through the interior of which exhaust steam from the feed and air pumps, and also some from the exhaust passage of the cylinders, is passed. The feed water circulates around the outside of the tubes and absorbs the heat from this steam. It then passes to a heater in the front end, which is designed along the same lines as used by the Baldwin superheater. After traversing a path approximately 25 feet long through these tubes and heaters, in which it absorbs the heat from the end gases, a deflector plate being provided to compel them to pass around the tubes before going to the stack, it is delivered to the boiler check valve located in the usual position on the lefthand side.

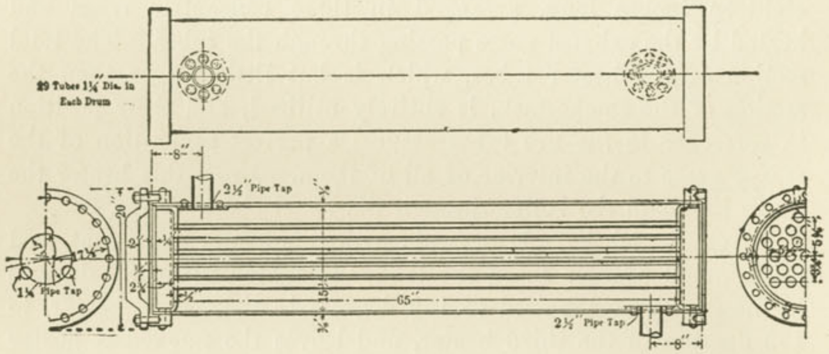


Fig. 2.

Gaines Feed Water Heater.

The water passing through the different heaters is driven at a very low velocity, not exceeding 16 feet per minute, and hence is given ample opportunity to absorb large amounts of heat. Although tests have not yet been completed to show exactly what temperature is attained at each stage, it is fair to assume from the figures obtained by Mr. Trevithick that water will probably be delivered to the boiler at something over 300 degrees; water or steam at 200 pounds pressure having a temperature of 387.5 degrees.

The principal objection to a heater of this design is the trouble which is experienced in the depositing of all of the in-

crusting matter in the feed water upon the tubes of the various heaters, so that they soon become seriously clogged up and make the arrangement useless. This difficulty has been considered in connection with designing this heater, as the locomotive is to be used in service where the water contains little hard scale-forming impurities. Since the temperature in the various heaters is comparatively low, there will be no tendency for this scale

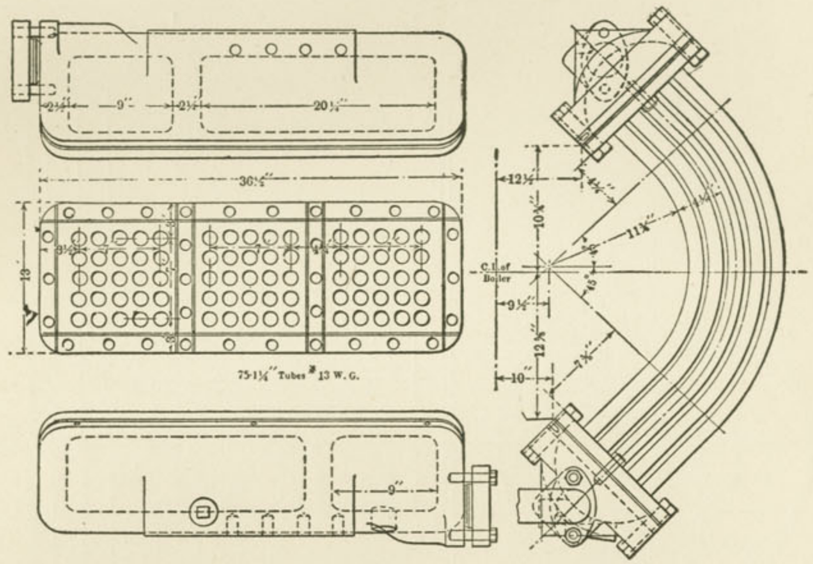


Fig. 3.

Section of Gaines Heater in Front End.

to bake on, and it may be easily washed out. Washout plugs are provided in the side heaters and the lower drums of the front end heater. Under conditions where bad water would have to be used, the heater may be designed so as to permit that section in which the largest part of the incrusting matter was thrown down to be removed and cleaned, which would thus give the heater a very large advantage because of its ability to keep these impurities out of the boiler itself.

Previous to the use of the Gaines feed water heater, the heating of the feed water had been confined to attempts to heat the water in the tank by means of the air pump exhaust, so that the present experiments being carried on on the Central Georgia Railway may be said to be a distinct advance in the improvement of heating the feed water.

Feed water heaters will no doubt require considerable attention at the terminals, and if the cost of maintenance and re-

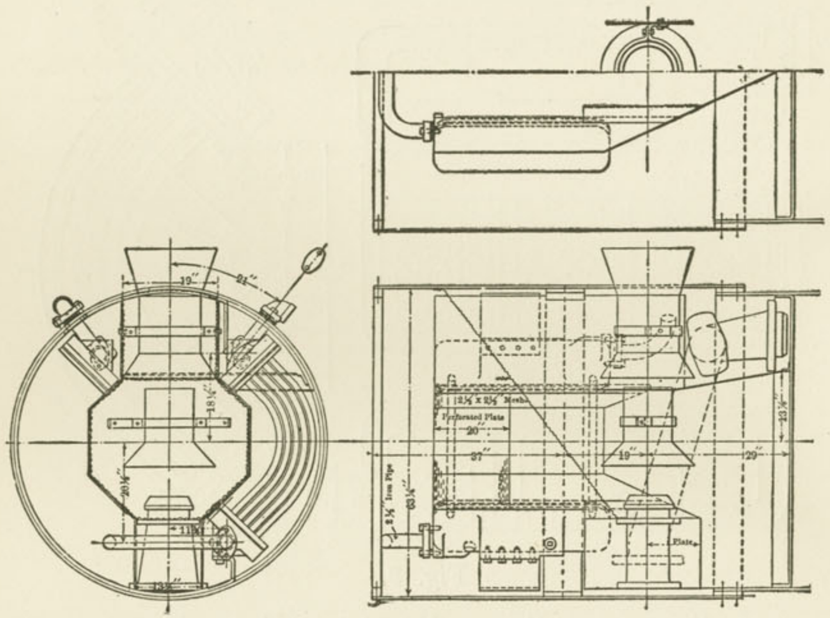


Fig. 4.

Position of Gaines Feed Water Heater in Front End.

pairs is of any considerable amount, it is probable that this type will never come into successful use, as the by-word of railroad engineers is simplicity. It may be, however, where softened water is used that a large part of the scale formed will be such that it can easily be cleaned from the feed water without much labor and expense. The possibilities of the feed water heater are very attractive, so that no doubt there will eventually

be some form of successful device for heating the feed water found on locomotives.

Feed water heaters are used on the large Mallet compound locomotives built by the Baldwin Locomotive Works for the Southern Pacific Railroad. In these locomotives the boiler tubes

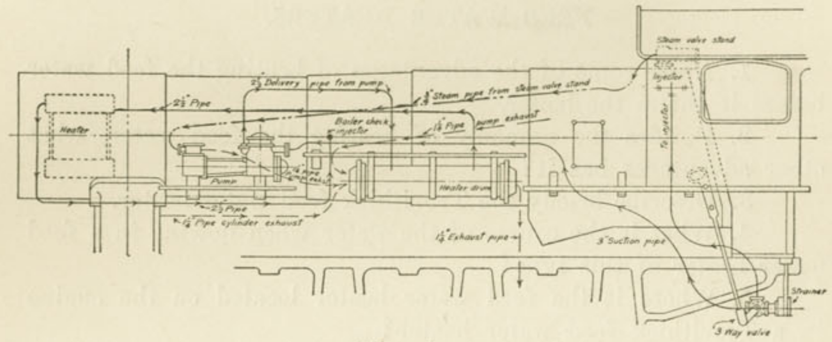


Fig. 5.

General Arrangement of Gaines Feed Water Heater, Showing Course Followed by the Water.

are 21 feet long. These tubes terminate in a combustion chamber, 54 inches long, in front of which is a feed water heater 63 inches in length. The tubes in the feed water heater are set in alignment with the fire tubes, and are equal to them in number and diameter.

REVIEW QUESTIONS.

FEED WATER HEATERS.

1. Name some of the advantages of heating the feed water before it enters the boiler.

2. Besides the economy of heating the feed water, what other advantages has it?

3. Describe briefly the Trevithick feed water heater.

4. What is the course of the water when flowing in a feed water heater of this type?

5. Where is the feed water heater located on the engine in a Trevithick feed water heater?

6. How is the water heated in this type, from the exhaust gases or from the exhaust steam?

7. In tests which have been made of the Trevithick feed water heater, what has been the estimated saving in fuel?

8. Name the principal construction features of the Gaines feed water heater?

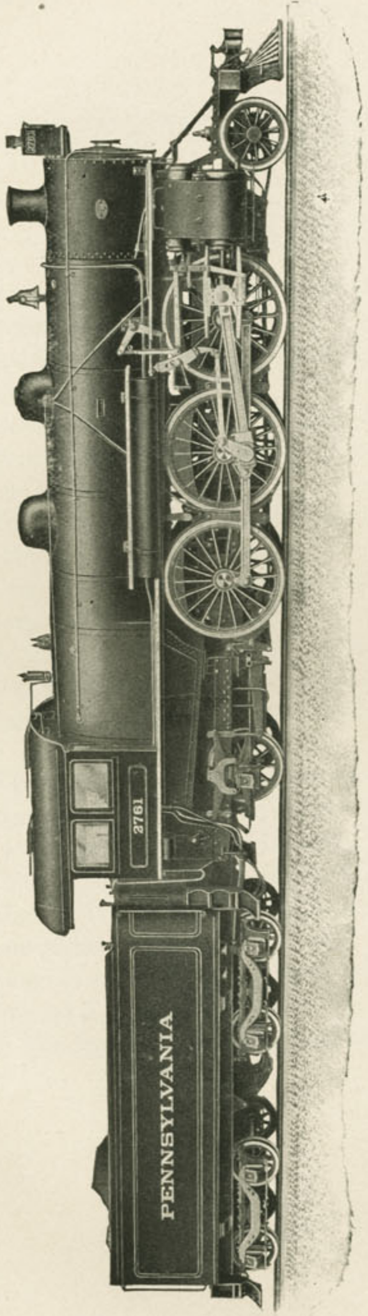
9. What is the principal objection to a heater of this type?

10. Describe how the feed water circulates and how it is heated in a Gaines feed water heater.

11. Where is the Gaines feed water heater located?

12. How is it that feed water heaters are not more generally found upon locomotives?

13. Describe the type of feed water heaters used on the Mallet compound locomotive built by the Baldwin Locomotive Works for the Southern Pacific Railroad.



PRAIRIE TYPE LOCOMOTIVE
(American Locomotive Co.)

Superheated Steam for Locomotives.

Among the improvements in locomotive construction none has excited greater interest in engineering circles than the application of highly superheated steam in locomotive practice. Ten years ago the possibility of having a temperature of 550 to 650 degrees F. within the restricted capacity of an ordinary locomotive boiler and its safe and economical application was not considered possible. At the present time, however, it has found successful application in more than 2000 locomotives. Dry or moderately superheated steam had been tried on different occasions, but without realizing any notable economic advantage in practice, and it was not until Mr. William Schmidt, of Cassel, Germany, had developed practical methods of applying high superheat that its use became possible in stationary engines about 1880. Fifteen years later the first steps were taken in extending it to locomotives, when it soon became apparent that an effective locomotive superheater could only be realized by making it a closely connected integral part of the boiler itself, receiving its heat from the live flames of the fire grate and not from waste gases or an independently fired apparatus, as had been previously tried.

Properties of Superheated Steam. The method of producing and using superheated steam will be much better understood by a preliminary consideration of the more important properties in which it differs from saturated steam.

The specific volume of saturated steam diminishes with increase of temperature, while on the other hand the volume of superheated steam increases nearly directly in proportion to the rise of temperature. The specific volume for superheat of 200 degrees is increased approximately 25 per cent, and thus, for the same cut-off in the cylinder, the weight of steam required is about 25 per cent less with 200 degrees superheat than with saturated steam with the same pressure.

This increase of volume is, however, a less important advantage than that realized by the suppression of all cylinder condensation when the superheat is sufficiently high. Under ordinary average working conditions about 35 per cent of the total quantity of saturated steam admitted into the cylinder immediately condenses without doing any mechanical work, and passes through the engine as suspended water in the steam. Highly superheated steam, on the contrary, does not lose any of its capacity as a working agent. This condition is augmented by the low thermal conductivity of the superheated steam.

Saturated steam is a good conductor of heat; highly superheated steam is a very bad conductor. This property, which is of great value in reducing the loss by cooling in the cylinders, is, on the other hand, an obstacle to the free transmission of the heat to the steam in the superheater, and calls for special consideration in its design.

In order to realize the great economical advantage of superheated steam, due to increased volume and avoidance of cylinder condensation, a certain heat expenditure must be used in order to effect the saving due to the above items.

The heat necessary to raise one pound of saturated steam from its proper temperature T to a higher temperature t is:

$$W_1 = C(t - T)$$

C being the specific heat of the superheated steam under constant pressure.

Letting W equal the quantity of heat contained per pound of steam saturated at this particular pressure, then $W_2 = W + W_1 = W + S(t - T)$ expresses the heat value of the superheated steam; that is, the total heat contained in one pound of steam superheated to the temperature t.

According to the latest researches the specific heat of steam

is not constant, but varies with the temperature and pressure, the mean values for the temperatures and pressures used in locomotive practice being about .677 for steam at 185 pounds pressure and 392 degrees F., and .536 for steam at the same pressure, but at 662 degrees F.

Requirements of a Superheater. The heat requirements of the superheater are not limited to the amount W_1 necessary for supplying the actual superheat, but must be supplemented by the quantity necessary for evaporating particles of water mechanically carried into the superheater. Assuming a degree of humidity in the boiler steam of 7 per cent, which for ordinary locomotive working conditions is certainly not excessive, the heat demand for the production of one pound of steam at 170 pounds pressure and 572 degrees F., temperature from the heating surface of the boiler and superheater, will be as follows:

	B. T. U.
From the boiler surface:—	
.93 lb. dry saturated steam=.93×1,194.3=.	1,111
.07 lb. water at saturation temp.=.07×340.5=........	24
	1,135
From the superheater:—	
Evaporation of .07 lb. water 368.3° F.=.07×853.8=	60
Superheating 1 lb. dry steam by 204°=.541×204=..	110
Total heat required for 1 lb. of hot steam=.............	1,305

of which 170 or 13 per cent is required from the superheater.

Assuming that 40 per cent of the total heat is developed in the fire-box and 60 per cent in the tubes, the superheating surface would therefore be 13 per cent of 60, or 22 per cent of the total tube surface, and when it is further considered that the best part of this surface nearest to the back tube sheet is unavailable, it is readily understood that, in order to obtain a sufficient superheater, it requires from 25 to 30 per cent of the total tube surface of the boiler. The superheating surface is not directly proportional to the degree of superheat, since to require half of the heat, or say 473 degrees F., considerably more work is called for than will be furnished by a superheater of only half the heating surface.

Generation of Superheated Steam. Steam with only a moderate superheat is generally mixed with particles of water or damp steam, the better conductivity of which will rapidly contaminate the whole mixture. In order to supply the heat to all parts of the steam, it is required that it shall be divided into numerous thin streams, which by combination with multiple reversals of direction will insure the thorough mixture of the moist and superheated particles. It is very necessary that a high temperature difference shall prevail. That is, the application of highly heated gases is essential.

According to recent experiments, an average temperature of 570 degrees F. in the steam chest must be obtained in order to insure the freedom of the superheated steam from saturated portions. Repeated trials have shown that the coal and water consumption is decidedly increased when the temperature falls to any extent below 570 degrees F.

Owing to the small available space in a locomotive boiler, successful superheating can only be realized by superheaters complying with the following conditions: 1. Application of a sufficiently high temperature in the heating gases. 2. The greatest possible subdivision of the superheater surface. 3. Mixing the steam currents on their way through the tubes and lengthening the passages, so that they are compelled after passing one set of tubes to return by another. 4. Guiding and regulating the draft of the heating gases.

Hauling Capacity with Superheated Steam. In addition to a saving in fuel and water, a further and more important advantage of superheated steam is to be found in the increased hauling capacity of the engine. In comparative trials of two locomotives the superheated engine has shown a saving of about 25 per cent of coal, each doing the same amount of work. It has also been found in practice that a superheater locomotive can be harder driven, doing more work than the other engine and still giving a smaller coal consumption.

Forms of Superheaters. The method of leading the currents, both of furnace gases and of steam, is of primary importance in determining the efficiency of superheaters. Care must be taken to protect the tubes from the cutting action of the flame, and the

counter cutter principle of bringing the coolest steam in contact with the hottest portion of the fumes is essenial. The question whether the tubes should be arranged transversely or parallel to the current of hot gases cannot be considered as finally settled. The experience with the stationary boiler, however, would indicate that the latter is more favorable to regularity in heating.

The superheater system must include the largest possible number of thick small bore tubes to allow of frequent intermixture of the currents, taking care, however, that steam that has already been superheated should not be brought into contact with that in a damp or saturated condition.

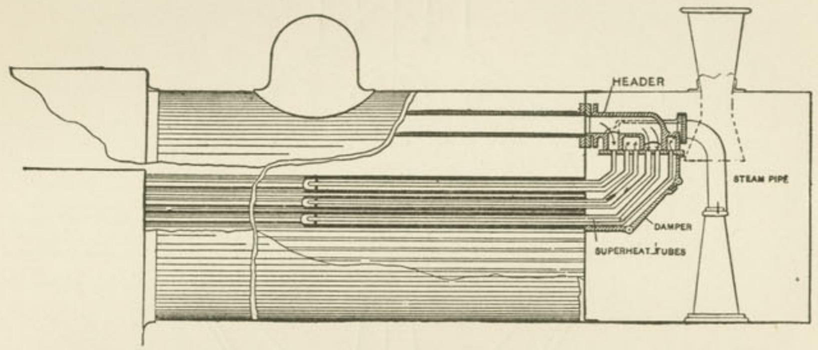


Fig. 1.

SCHMIDT SUPERHEATER.

The velocity of the steam in the superheater must be tolerably high in order to prevent overheating the tubes. The upper limit of such velocity is determined by the permissible fall in pressure, and is considerably higher than with saturated steam, on account of the increased fluidity due to the complete gasification.

The first practical locomotive superheater used in this country was of the Schmidt smoke-box type, and was used by the Canadian Pacific Railway in 1901. This superheater consists of a series of circulating or superheating tubes placed in the lower part of the boiler. This form of superheater gives a high decree of superheat, but its expensive and complicated construction and its inaccessibility for repairs make it undesirable for general locomotive work.

Schmidt Superheater. Another form of superheater, also of the Schmidt design, is known as the smoke-tube type, and is shown in Figs. 1 and 2. This type has been used on several engines for a number of years, and is said to give entire satisfaction, showing, as it does, a saving in fuel over engines of like build. Its construction is as follows: A double chambered header ex-

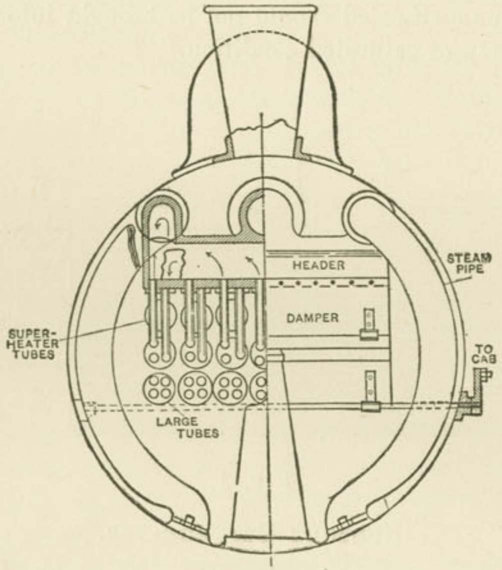


Fig. 2.

END VIEW OF SCHMIDT SUPERHEATER.

tends horizontally across the front flue sheet and at right angles to thed ry pipe, to which one chamber is connected, while the other chamber is connected to the other end with a steam pipe. The under surface of this header is faced and in it are eight series of ports or openings, the alternate ports in each series leading to one of the two chambers. To this under surface are suspended by means of straps, bolted to the header, square blocks, into each of which are secured two seats or pairs of circulating or super-

heating tubes. These circulating tubes extend downward at an angle to a point in line with their respective smoke tubes, where they turn and enter the smoke tube to within thirty inches of the back flue sheet. At the fire box end a return bend is applied to make a connection between two circulating tubes, one leading from each of the chambers and secured to the same block. Thus

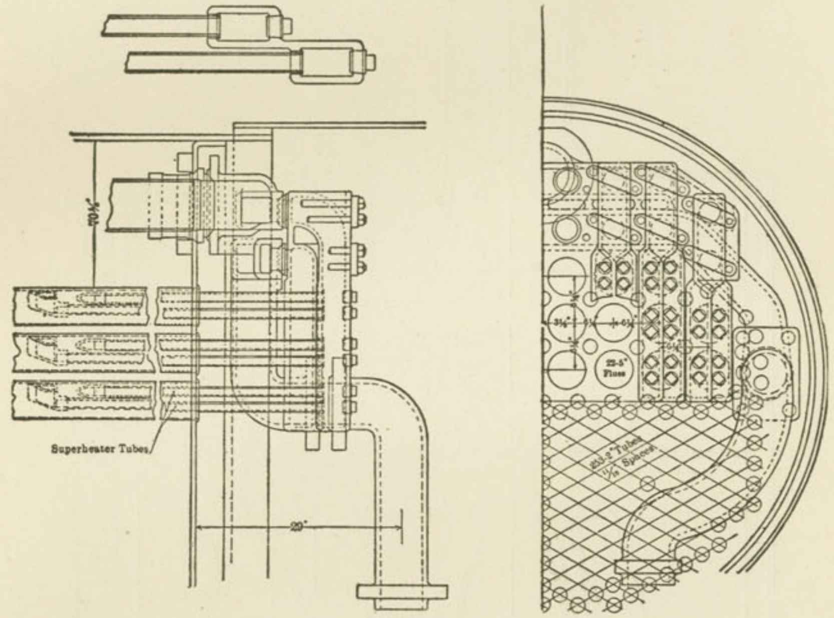


Fig. 3.

COLE SUPERHEATER.

the steam, leaving the dry pipe passes through one chamber of the header out through one circulating tube and back through its complementary tube. It then goes through the other chamber of the header to the steam pipes, and then to the steam chest.

Cole Superheater. Another type which is used is known as the Cole superheater. This design consists of eight double-chambered headers, which are secured by four three-fourths inch bolts spaced six inches apart to the niggerhead. These headers extend vertically downward in front of the top sheet, and the circulating tubes are entered from the back on a line with the smoke tubes, through holes in the back wall of the header chambers, and are

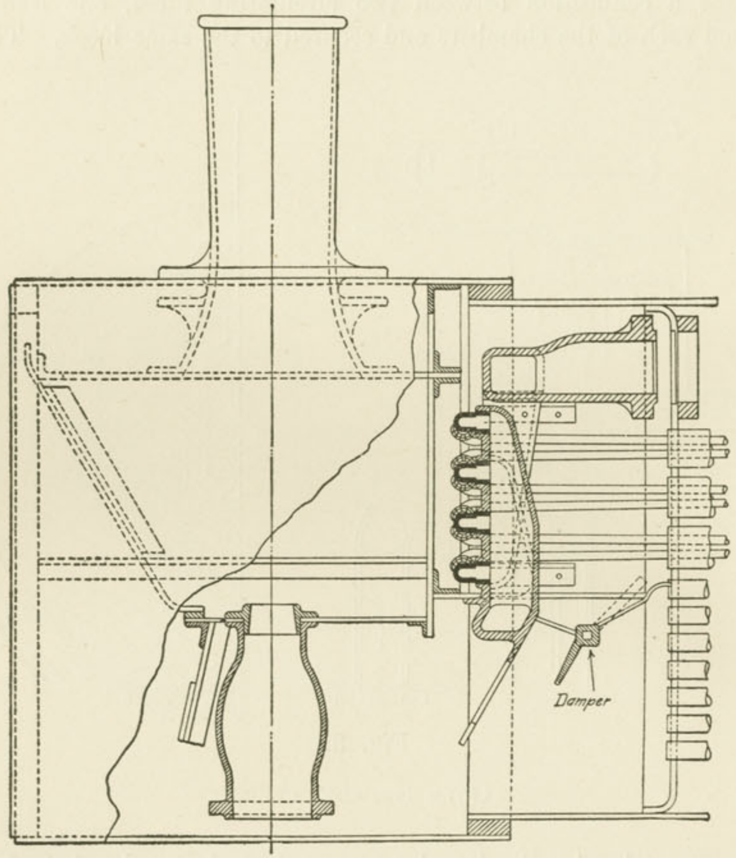


Fig. 4.

Vaughan-Horsey Superheater.

thus made steam-tight. A plugged hole in the front face of the header permits the expanding and fastening of the ends of the tubes in the heater, as well as the plugging or working on them in case of their becoming ruptured or leaky. This type has

been improved in design by using a differently constructed header with a more substantial fastening to the niggerhead. This design is shown in Fig. 3. The two chambers of each header are independent walls, and are joined together by a web.

Vaughan-Horsey Superheater. A somewhat different design of superheater is known as the Vaughan-Horsey superheater. With this arrangement there are two elongated chamber castings,

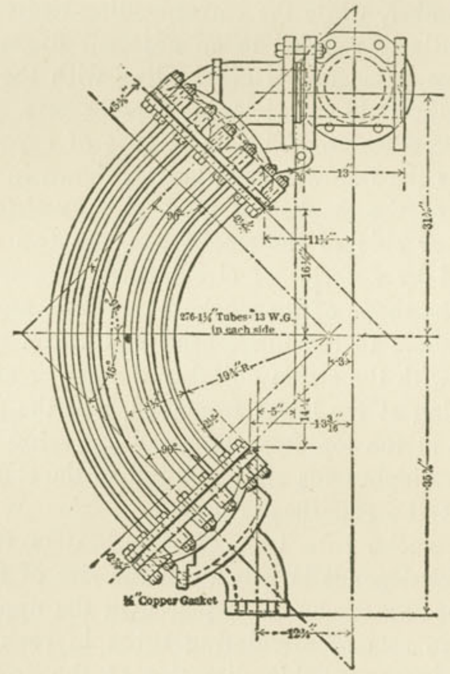


Fig. 5.

Baldwin Superheater.

each entirely independent of the other, and each being cast with a series of fingers which act in the capacity of headers. One chamber casting, which acts as a niggerhead, is bolted centrally to the dry pipe in such a manner as to have the fingers extend vertically downward, while the other chamber casting, fastened at either end to a short steam pipe, has its fingers extending upward.

These fingers, when in position, interlace, but with sufficient space between them to permit the introduction of the circulating tubes. This arrangement is shown in Fig. 4. One end of the circulating tubes has a collar upset on it, and the end of the tube is then so bent that the milled face of the collar will be parallel to the length of the tube. With a steel union nut the bent end of the circulating tube is secured to a drop forged two or four-way passage, which is secured into the upper face of one of the fingers of one chamber, while the corresponding end of the companion tube is similarly secured to an adjacent finger of the other chamber. These passageways are in line with the smoke tubes, the same as in the Cole and Schmidt superheaters.

Baldwin Superheater. The latest type of superheater which has been used is the Baldwin superheater, shown in Fig. 5. This superheater is of the smake-box type, and consists of only two headers on either side of the smoke box, the two on either side being connected by a series of circulating pipes which are bent to conform to the shape of the smoke box. Two methods for connecting the headers to the niggerhead and steam pipes are provided for, one with the steam entering the heater at the top back end and emerging at the lower front end, and the other with the steam entering at the top front end and emerging at the bottom back end. The diaphragms are employed in the stack to circulate the gases about the superheater tubes.

With the smoke tube type of superheaters the number of circulating tubes depends largely upon the size of the boiler, and it is usual to use 22 smoke tubes placed in the upper part of the boiler, with two sets of circulating tubes in each. The smoke tubes are five inches outside diameter at the front sheet, into which they are expanded and beaded over. This diameter is maintained to within seven inches of the fire-box end, where it is wedged down to four inches, and enters the sheet at that diameter. The hole in the fire-box sheet is threaded, and the tube is screwed into the sheet and then beaded over. The circulating tubes are all cold drawn steel, one and one-quarter inches outside diameter, and extend into the smoke tube to within 30 inches of the fire-box, where the return bend joins the two tubes together, and all four circulating tubes are separated, as well as being supported in and

held away from the walls of the smoke tube, so as to permit the circulation of the gases. To protect the tubes, when no steam is passing through them, a damper is placed in the front end immediately below the large smoke tubes and between the superheater and flue sheet. This damper opens and closes automatically with the opening and closing of the main throttle by means of a cylinder piped to the steam way in the cylinder saddle, and a piston and weight attached on the outside of the smoke-box to an extension of the damper rod.

Lubrication when Using Superheated Steam. One of the difficulties which has been experienced with superheated steam is that of getting oil to the valves and pistons; but recent experience has demonstrated that, when properly piped, the hydrostatic lubricator will deliver oil in sufficient quantities at all times, and that the usual amount of the better grades of valve oil is sufficient for lubricating valves and pistons. There are several methods of oiling valves and cylinders when using superheated steam. One method is to use an independent pipe to the valve chamber and cylinder, while another is to feed all the oil through the steam chest and cut out the feeds to the cylinder. It has been found on engines of the Canadian Pacific Railroad that there has been very little trouble due to the wear of the steam chest and cylinders; the principal cases of excessive wear being in the packing rings, due partly to insufficient lubrication and partly to soft material.

Experience with Superheaters. The principal experience with superheaters has been chiefly on the Canadian Pacific Railroad, where there are several hundred in use, and it is due to this experience that the defects of the superheater have been removed. According to their experience with various forms of superheaters described above, they have found that the Schmidt smoke-tube design has required the least attention when once the equipment is made steam-tight. The most trouble with the several designs has been with the Cole, which has failed to give a very high degree of superheat and often becomes overheated, the tubes blistering and blowing out.

With the Vaughan-Horsey type a higher degree of superheat is obtained, and the defective parts are more readily repaired and renewed, the chief source of trouble being that the circulating tubes are liable to leak. The more recent designs, however, of this type have made failures less frequent, while it is expected that with the more increased use of not only this type, but all other types, the superheater will become an apparatus of standard design and reliability.

The Value of Superheat in Reducing Condensation. When using saturated steam in the engine cylinder, there is considerable condensation of the entering steam, which is later evaporated and passes through the cylinder without doing any work, and which may even, if the piston speed is sufficiently high, remain as water in the cylinder. This amount may be considerably reduced when a sufficient degree of superheating is adopted. With superheated steam, there is a surplus of heat above the saturation temperature, and while the steam is somewhat cooled, it is not sufficient to cause condensation. During the exhaust the heat demand on the cylinder walls is comparatively small, especially when a slight superheater still remains, partly because such steam is a poor conductor of heat, and particularly because such heat is directly applied to raising the steam temperature and not for evaporating water. The use of superheated steam, therefore, is attained with a much smaller heat interchange, and the mean temperature of the cylinder walls is kept at a higher point. Only by a very high initial superheating of the steam can cylinder condensation be prevented during the entire working stroke, and this has been objected to on the ground that with such excessive heating the superheat is not entirely expended, and the exhaust passes out at an unnecessarily high temperature. Upon these grounds it has been proposed to limit the superheat so that at the end of the stroke the exhaust will be in a saturated state. The constantly varying demands upon both the boiler and engine of a locomotive necessitate a considerable margin in the power of the superheater above that calculated for normal use, and it would hardly be satisfactory to design a superheater to give this condition. Numerous trials have shown that the greatest economy is invariably obtained with the highest steam temperature, notwithstanding the increased temperature of the exhaust steam consequent upon its use.

The difficulties anticipated by many railway experts, as

likely to arise from the working parts when continuously running under highly superheated steam, have not, in the large number of locomotives now in use, given rise to any practical inconvenience. Minor difficulties have been completely overcome, and forms of pistons, piston valves and stuffing-boxes are used, which have since proved to be perfectly durable under the highest steam pressures. Lubrication troubles have been eliminated by the use of oils of a sufficiently high flash point, combined with a simple method of oiling under pressure.

Repair of Defective Tubes. Should one of the circulating tubes of the Schmidt smoke-box type become defective, the trouble must be located, the front end must be torn down and the defective tube replaced. With the Cole type a defective tube, when located, may be plugged by removing the plug from the front face of the header and inserting a plug through the hole into the circulating tube. This, however, is only a temporary repair, and when the tube is removed it necessitates taking down the header with the other circulating tubes attached to it. With the Vaughan-Horsey type a defective tube may be repaired by removing the front bolts, uncoupling the defective tube, and screwing a cap on the passageway until a new tube is inserted. Defective tubes may be located by means of water, the same as locating a leaky steam pipe.

Cleaning the Tubes. Unless the cleaning of the tubes in superheaters is thoroughly and regularly done, there will be a considerable deterioration in the efficiency of not only the superheater, but of the engine itself. With any kind of soft coal, cinders are bound to collect in the large smoke tubes and fill in and around the circulating tubes, and it is found that the air blast usually applied is not sufficient to remove them. A strong pressure of water is therefore necessary to thoroughly cleanse the tubes, and this should be resorted to at least at every washing out of the boiler. Circulating tubes which have been examined after an extended service in superheaters have been found to be incrusted with from one-sixteenth to one-eighth inch of soot, and it is recommended that a sand blast be resorted to occasionally to remove this soot, the same as in oil-burning engines.

Operating Superheaters. In the ordinary operation of an engine containing a superheater, the engineer must see to it that the superheater damper is properly working at all times. If the damper sticks in the closed position, the superheater is useless, and the total heating surface of the engine may be materially reduced. If the damper sticks in the open position, there will be a deterioration of the superheater tubes, resulting in their finally breaking and causing an engine failure. While the engine is working the circulating tubes should, when conditions permit, be kept full of steam at boiler pressure, and to accomplish this the engine should be worked with a full throttle and the cut-off regulated to suit the conditions.

The Atchison, Topeka & Santa Fe Railway has a number of Pacific type and Consolidation type engines with superheaters, some of which are equipped for burning coal, and some are arranged for burning oil. These locomotives carry a boiler pressure of but 160 pounds, and are fitted with very large simple cylinders, so as to take advantage of the full adhesive weight with this low boiler pressure. The difficulty from condensation, which would be greatly increased because of the large increase in the area of the walls in these cylinders, has been reduced by the installation of smoke-box superheaters in all of the locomotives. The superheaters are of the Baldwin type, and are not intended or expected to deliver highly superheated steam, but simply to give sufficient superheat to overcome the excessive condensation. The principal advantage gained by this arrangement is the reduction in boiler troubles and ease of maintaining full pressure, especially in bad water districts where great difficulty has been found in keeping boilers tight.

The superheater is arranged on the Pacific type engines so that the saturated steam enters the superheater at the front end and works backward, the final outlet being at the end nearest the front tube sheet, or at the point where the hottest gases are found. It has a heating surface of 709 square feet. The superheater on the Consolidation locomotives has a heating surface of 600 square feet.

Economy of Superheating. The saving in coal, due to the suppression of cylinder condensation, with a simple superheated engine approaches about 25 per cent when compared with that of a saturated steam locomotive of the same weight, and to 15 or 20 per cent when compared with a two or four-cylinder compound. For practical locomotive purposes coal consumption alone can be relied upon for comparison under present conditions. Rules have been given at various times for determining the saving available; but these are all based on the assumption that the saving increases uniformly with the superheat, which, however, is not borne out by test, as a large saving is not realized with less than 100 degrees of superheat, and above that point it increases very rapidly.

Tests of a medium pressure simple locomotive with superheated steam made on the Atchison, Topeka and Santa Fe Railway show that an economy in operation of within 5 per cent of that of the high pressure compound locomotive can be secured, while the boiler troubles from the high pressure and the extra maintenance of the compound gear are avoiled. The engine under test had 32″x32″ cylinders and ample boiler capacity, the pressure used being from 130 to 150 pounds, with from 30 to 40 degrees superheat. The engine required less repair work than compound engines of similar size, and also handled much more satisfactorily the bad foaming waters of New Mexico.

OPERATION AND MAINTENANCE OF SUPERHEATER ENGINES.

The following recommendations, as to the operation and maintenance of superheater engines, were made by the committee on superheating in its report at the recent meeting of the Traveling Engineers' Association:

In the operation of the superheaters the following suggestions should be carried out:

1. When working steam, open throttle valve fully and regulate with cut-off. . . .

2. Keep water level in boiler as low as in saturated steam engines.

3. Ascertain that dampers (where equipped) in smoke-box are working properly, also that the small steam cylinder actuating these dampers is not leaking through stuffing-box.

4. Be sure that oil is carried from lubricator to each end of valve and also to cylinder.

5. Any leaky steam joints at cylinders or valves should be tightened, and if connections or joints of superheater proper should be found leaking, report at once at end of run.

The work of maintaining and taking care of the superheater in the roundhouse is enumerated in the following:

1. Keep all steam joints and connections of superheater, as well as cylinders and valves, tight.

2. Piston and valve rings should have a close fit to cylinder walls and valve-bushings respectively.

3. Clean or blow out large smoke flues whenever necessary. The more attention paid to this work, the more economy will be attained with the engine.

4. The ends of the large smoke flues which originally were screwed in the fire-box flue sheet, and have given trouble by leaking, should be rolled and expanded.

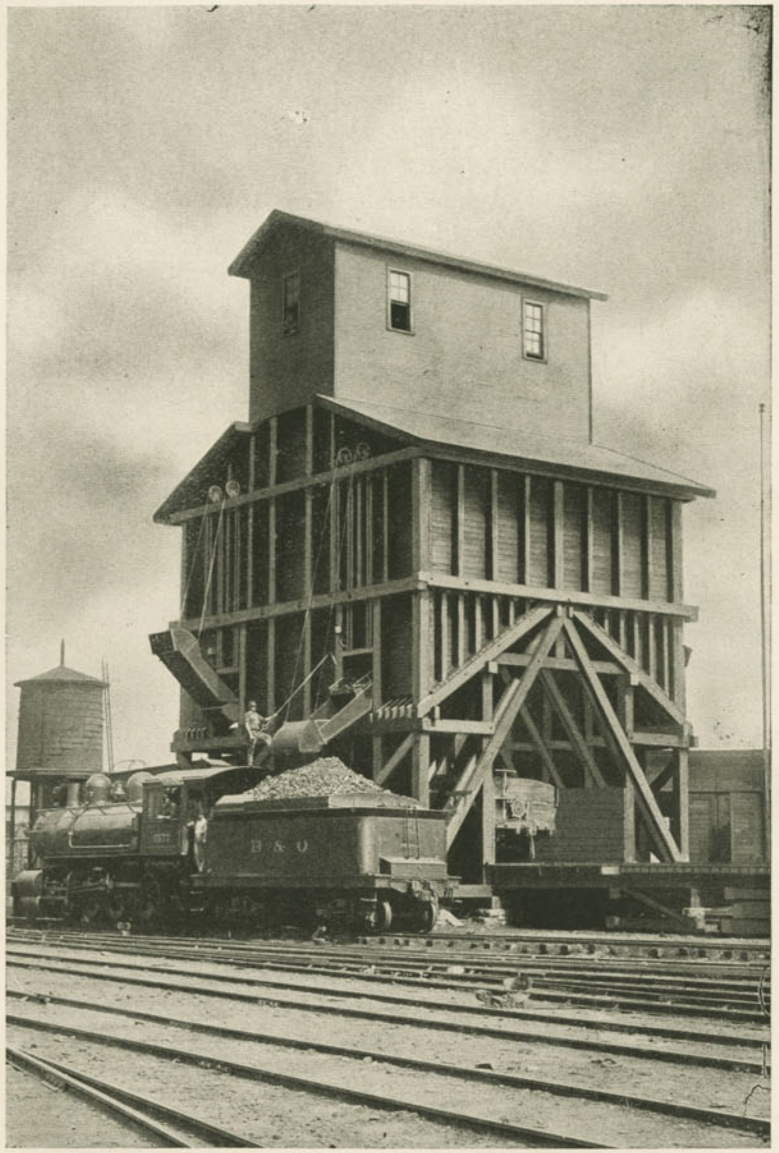
5. In renewing tubes of superheater elements, use only seamless cold drawn steel tubing. See that they are put in correct length, otherwise, due to contraction and expansion, the connections in the U-bent castings will work loose and leak, or tubes will split.

6. The ends of the superheater elements nearest to the fire-box are supported by lugs or legs of the U-bent castings. Due to the expansion and contraction of these elements, these lugs ride or chafe the bottom of the large smoke flues. Ascertain if this riding or chafing has weakened the large tube. If so, renew the tube.

7. Pay attention to the dampers, their lever connections and the small steam cylinder. Pack the latter whenever necessary, as any leakage will be detrimental to the operation of the dampers. See that all hinges of dampers, also the lever connections, are in good working order.

8. The lubricator should be tested whenever necessary.

9. Injectors must be connected with saturated steam. They will not work properly with superheated steam.



500-TON COALING STATION USED ON THE BALTIMORE & OHIO, LAKE SHORE & MICHIGAN SOUTHERN, NEW YORK CENTRAL AND ERIE RAILROADS.
(Link-Belt Company)

Locomotive Coaling Stations

Locomotive tenders are supplied with coal in various ways. On the very smallest roads, the coal is sometimes shoveled from cars alongside of the tender; but it is most usual to find some mechanical arrangement which loads the tenders automatically.

On large roads, especially at the terminals, the subject of the proper handling of the fuel is a very important one, as fuel for locomotives is the largest single item of expense in the cost of conducting transportation on most American railroads, the cost varying from 8 to 17 per cent of the total operating expenses.

It is therefore natural that the railroads are devoting considerable time to the inspection, handling and economical use of the coal used. The fuel resources of this country are not unlimited and the cost of fuel is advancing. Reduced rates and increased cost of labor and material make it necessary for the railroads to study possible economies closely, and there is no more promising field than the handling and use of fuel on the locomotive.

Advantages of Coal Handling Apparatus. Coal handling apparatus may be adapted to any location or arrangement of tracks, owing to the flexiblity of arrangement and the comparatively little ground space which is required, so that it is particularly available for terminals where space is limited and valuable. It permits of the establishment of an abundant supply in or near the center of the terminal, or in such a position that locomotives in passing, whether on the yard or through the service tracks, can receive coal without shifting or switching or without appreciable delay. A single station will serve locomotives on any number of adjacent tracks simultaneously and in less than one minute. It also enables the locomotive to receive sand and water and discharge cinders while receiving coal. A coal handling apparatus will store and deliver to tenders hard or soft coal of any size, and both kinds mixed in any desired proportion. It will measure or weigh and record the weight of each amount of coal delivered, which feature is especially desirable where two or more roads unite for terminal purposes.

Rquirements of a Locomotive Coal Plant. The requirements of an economical coaling station for locomotives are as follows:

A locomotive coaling plant should minimize delays to engines while coaling; delays to coal cars; the cost of handling coal; it may also be desired to accurately measure the coal as delivered to locomotives.

An ample storage capacity insures against delays, due to interruption of coal supply, to bunching of engines and to breakdowns, derailments and necessary repairs. At important points, it is sometimes desirable to provide duplicate machinery.

The roundhouse track arrangement should be as compact as possible and at the same time allow the necessary free movement. The question of the proper location of the coaling plant with reference to the cinder pit depends upon the type of plant adopted. In cold weather, delay to the engine after the fire is cleaned is liable to cause leaking, though some of the trouble attributed to this cause is probably due to an unwise use of the injector.

Providing storage room so as to cut down the delay of cars as much as possible is very important.

A coaling plant should be designed to take care of all the coal to be held for emergencies, so that cars can be released promptly upon arrival. That is, of course, not always feasible.

All plants for self-clearing cars should have the hoppers wide enough so that the coal can be shoveled from flat bottom cars by hand if desired, and so that side dump cars can be used.

Self-clearing cars can be unloaded into a hopper for less cost than unloading flat bottom cars by hand, and should be used when possible.

The Grade of Fuel to Use in Locomotives. One of the most important considerations in connection with the question of fuel economy is the selection of the proper grade of fuel. It must be fairly uniform in quality, or it will be impossible to use it economically. A front end arrangement, or grates suitable for one grade of coal, may be entirely unsuited for another, and the fireman cannot obtain good results where the grade of fuel is constantly changing.

There is a great difference in the heat value of different coals, and while the subject has been given very little attention by most of the railroads, it is of prime importance. It is of interest to note that as a result of coal tests made at St. Louis by the United States Geological Survey, the Government is purchasing coal for about forty departmental buildings in Washington, and for public buildings throughout the country, on a simple specification, the prime elements in which fix the amount of ash and moisture in anthracite at seven per cent. Premiums are paid for any decrease in the ash content up to two per cent above the standard, and corresponding penalties are fixed for any increase in ash above the standard. Better and more complete specifications, but more difficult for the dealer to fulfill, have been fixed by a few of the largest manufacturing and power concerns of the country, in which penalty and premium are paid not only on account of ash and moisture content, but also on the basis of the British thermal units as specified in the contract.

It is possible, on a railroad, to make simple evaporative tests, in actual service, by which the comparatve heat values of the different coals may be determined. These results will enable the railroads to place their coal contracts to the best advantage.

Methods of Handling Fuel. Where the quantity of coal handled is small, and especially at terminal points where the engines lie over night and the coaling can be done by the hostler or watchman, coaling direct from the cars is the cheapest. This work can be aided by elevating the track on which the coal cars stand from two to four feet above the locomotive track.

Shoveling from the coal car direct into the locomotive has the advantage that it delivers the coal in the best possible condition. Crushing, due to handling, is kept at a minimum, and large lumps can be broken up ready for the fire by the shoveler. The tendency of large bins to separate the slack from the lump is avoided.

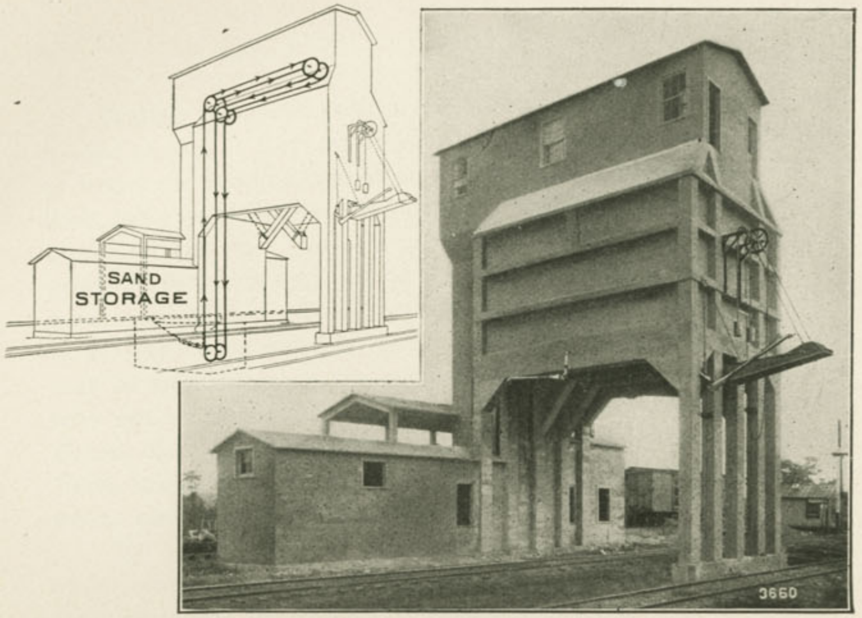
Coaling from Cars with a Jib Crane. Where the engines are needed as soon as they can be cared for, where they come bunched, or where the hostlers cannot do all the coaling in connection with their other work at the time desired, in addition to the elevated track, an elevated platform with buckets of about one ton capacity, into which coal can be shoveled at different times, may be used to advantage. These buckets may be raised by a jib crane, which can be operated by hand or by air from the engine, and may be emptied when the engines come too fast for the men to take care of them. By this method the cost can be kept down to almost that of coaling direct from the cars into the engines. These buckets can be used for emergency coaling stations enroute where coal is only occasionally required.

By having, instead of buckets, small dump cars on an elevated platform, and the coal car track considerably above the track on which the locomotive stands, more engines can be coaled quickly.

Williams-White Type. By still further increasing the elevation, the shoveling can be done directly into bins, by which the amount stored can be increased and a larger number of engines accommodated promptly. These bins can be filled with different amounts of coal, so that, by selecting the bin, the amount needed can be obtained. With all of the designs, thus far considered, flat-bottom cars are practically necessary.

Trestle Type. The next step is the construction of the high trestle, with the coal car track on top of the storage bins, thirty or forty feet above the engine track. The cost of switching is increased, but by the use of self-clearing cars, the cost of delivering coal from the cars to the bin can be almost entirely eliminated. The maximum grade of the approach desirable is usually considered as five per cent. Where the coal is not shoveled, this type of plant keeps the breakage of the coal at a minimum of all plants where the coal is not shoveled by hand. In considering the expense of operating these plants, the cost of placing the cars on the trestle by a locomotive, an expensive and dangerous operation, is not ordinarily included.

Power-operated Trestle Type. Instead of using a locomotive to place the cars, these plants can be equipped with a hoisting engine, allowing the use of a twenty per cent grade. The ma-



REINFORCED CONCRETE COAL AND SAND STATION, NORFOLK & WESTERN RAILWAY, CONCORD, W. VA.
Capacity, 260 Tons Coal, 10 Tons Dry Sand and 100 Tons Wet Sand.
(Link-Belt Company)

PENNSYLVANIA RAILROAD COAL AND CINDER STATION
Located at Gray's Ferry, Phila. Sixty Locomotives are Handled a Day
(Link-Belt Company)

chinery costs less than the trestle approach, much ground space can be saved and the operation is cheaper and safer when the cost of switching is considered. This type ordinarily increases the possibilities of providing storage room and does away with a considerable liability to accident.

Where two or more tracks are to be served and the necessary room is available, the coal car track can be put at right angles to the locomotive tracks. In some cases, where it is desired to coal on four tracks or on two main tracks, duplicated plants are constructed.

The trestle types are handicapped by the fact that the structure must sustain heavily loaded cars and also either locomotives or have power available to raise the cars. The costs per ton for maintenance are higher than is generally assumed, and if a fireproof structure is built, it would be expensive. They ordinarily cannot be placed in the most desirable location, and are not available in many cases where the room is cramped.

Locomotive Crane Type. At terminals where the demands are not too great, coaling can be done by means of a locomotive crane handling the coal direct from flat-bottom cars to a locomotive. This crane can also help switch coal cars, if necessary, and can handle cinders and sand. To allow the use of drop bottom cars, a pit can be constructed from which the crane can handle the coal. To avoid delay of locomotives, a trestle can be constructed on which the crane can work, so that it can load direct into bins, in which a fair amount of storage room can be provided. The bins are not protected from the weather, and the coal and gates are liable to be frozen up.

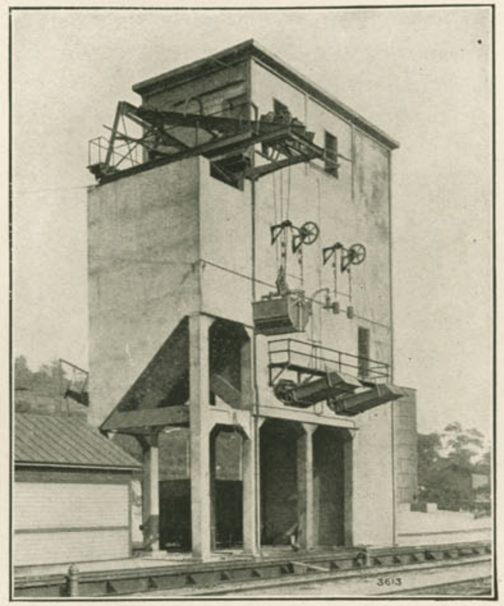
With the necessary tracks, the pit and the hoppers, it will be found that this sort of a plant has a considerable first cost. Its cost of operation depends upon the work which can be provided for the crane at spare times. Its value is great in emergency situations and at points where, because of impending changes, the construction of a permanent plant is unwise.

At a large terminal, where the conveyor plant is used, a locomotive crane would be very valuable to handle cinders and sand and also coal during a possible breakdown of the conveyor. The practical limit of a locomotive crane is said to be about 70 engines a day. The fact that it can unload direct from a flat-bottom car is much in its favor.

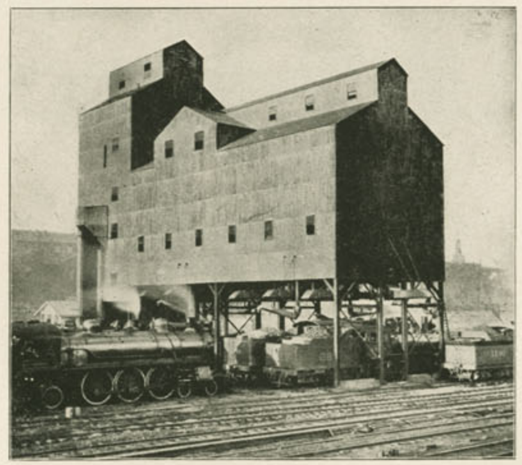
Clam-shell Bucket and Trolley Type. A type of plant using a special bucket of the clam-shell type operated on a trolley has been suggested. This can handle coal direct from a pit or from flat-bottom cars into bins over the tracks, and can also handle cinders. While this device has not yet been tried for coaling locomotives, it is receiving more or less attention, and will undoubtedly be tested soon. The number of tracks it can serve is unlimited and the mechanism is simple. The horse-power required is small and the first cost is not excessive. This type would be especially valuable where self-clearing cars cannot be regularly obtained and where large storage is desired. It is believed that with a plant of this type coal can be handled from flat-bottom cars at a reasonable cost. There should be no difficulty in getting an actual working capacity of seventy-five tons an hour, which is ordinarily ample.

Balanced Two-bucket Hoist. When the space is more or less limited, and the amount of coal to be handled and stored is not too great, and deep foundations can be constructed, the coal can be lifted into bins by means of two large buckets, operating opposite each other, so that when one is lowered the other is raised. The coal is delivered into the buckets by gravity from the bottom of a pit under the coal car track through a gate worked by the operator of the bucket. The bucket is automatically dumped into the bins at the top. It requires the continuous attention of the man operating it, but is an efficient machine where the requirements are not too great. The storage room in the bins is limited by the fact that this plant has practically but one point of delivery into the bin.

Link-belt Type. The bucket conveyor of link-belt type requires a small ground space, has great flexibility of adjustment to suit different conditions, and can be used for almost any situation desired. With the softer grades of bituminous coal, such as that from the Indiana fields, these plants tend to break up the coal. Many of these plants are in operation, and, where well cared for, are giving excellent service. This type of coal handling apparatus is shown in Fig. 1. The expenses of power and repairs are not great, and, where the conditions are such as to recommend their construction, they give good service at a reasonable cost.



REINFORCED CONCRETE COAL AND ASHES STATION
Pittsburg & Lake Erie Railroad Co., Pollock, Pa.



LOCOMOTIVE COAL AND CINDER STATION
Located at St. Louis, Mo.
(Link-Belt Company)

Robbins Belt Type. Plants raising the coal on a continuous belt of rubber and cotton on an incline of about thirty degrees are coming into use. The maintenance cost is reasonable, and

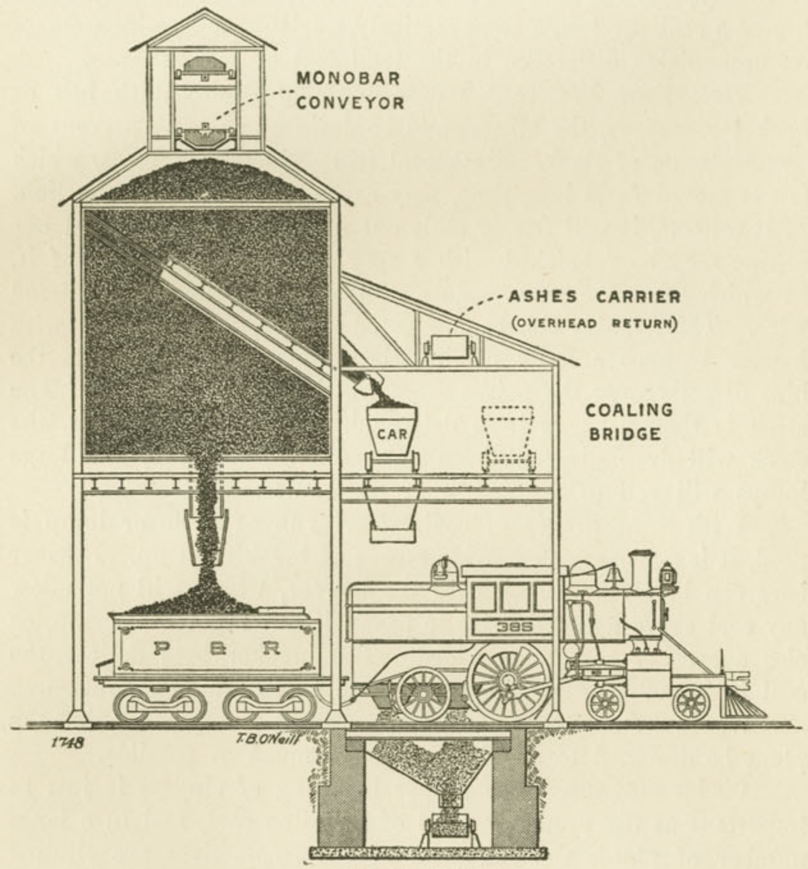


Fig. 1.

ENGINE TAKING COAL AND CLEANING ASH PAN SIMULTANEOUSLY.

in most situations it can be as readily fitted in as any other type. In some locations, where ample space is available, a better stor age yard for coal cars can be provided with this than by any other type, as the receiving hopper can be placed at a considerable distance from the storage bins in any direction. There are very few parts of this which can get out of order. The ordinary objection to this type is the expense of belt renewal, but this is only about 0.2 of a cent per ton, a comparatively small amount, which makes an appreciable difference in the total cost of maintenance.

Precautions Necessary When Handling Coal. With belt or bucket conveyors, the bins should be designed so as to prevent an accumulation of slack. Slack coal in considerable masses, which is not moved for a long time, may cause spontaneous combustion. If it collects, it will finally slide out in large masses, so that one engine may be furnished with a very considerable amount of it, in which cases the performance of trains is seriously interfered with. This trouble can be prevented by designing the bins with hopper bottoms and by placing the points of delivery into the bins directly over the points from which the coal is taken. The slack is then used as it is delivered. If this is not done, the slack will drop directly from the points of delivery, and large lumps will roll to the mouth of the chutes.

With some grades of coal, where run of mine or lump is used, it is necessary to provide means of breaking it up. Breaker bars can be either placed over the hopper, which will not allow any coal above a certain size to pass without being broken up, or else a crusher can be provided. The breaker bars deliver the coal in better condition, but are more expensive in operation.

Where softer grades of coal are used, it is important that the plant be designed to avoid breakage as much as possible.

Cinder Stations. The proper handling of cinders is just as important as the proper method of handling coal, and in a large number of plants the ash pans of the locomotives are cleaned while the locomotive tender is being coaled. One arrangement for doing this is shown in Fig. 1, in which the engine is shown taking coal and cleaning the ash pit simultaneously, and the method of delivering coal to the car on the bridge is also shown. An arrangement which shows eleven engines taking coal, seven of which are dumping ashes, is shown in Fig. 2. With this arrangement a car takes ashes from the ash bucket and a car delivers coal to the elevator, which in turn is delivered to an overhead distributing conveyor. The method of handling cinders shown in Figs. 2 and 3 consists of a steel bucket lined with concrete and having overhead trolley tracks spanning one or more cinder pits. The locomotive discharges fire box cinders and flue dust simultaneously into tubs, which are then elevated and dumped into the pocket.

Sand Stations. There is often a sand station connected with coal storage plants. The general arrangement consists in having the sand storage bin, the sand dryer, the engine and boiler, in

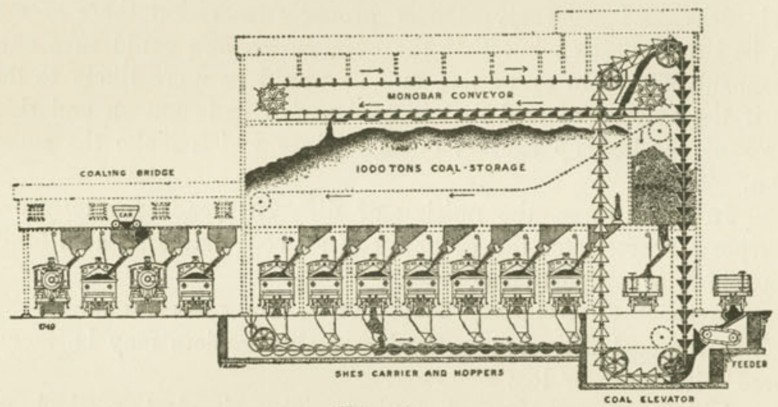


Fig. 2.

Coaling and Ash Handling Plant. Eleven Engines are Taking Coal, Seven of which are Dumping Ashes.

the opening in the base of the coal pocket. The sand is transferred from the wet storage to the sand dryer as needed, and it is then fed to a small belt bucket elevator, which evelates it to the top of the pocket and discharges it through a spout into the dry sand bin.

Reinforced Concrete Stations. The liabilities of a coaling station catching fire, either from spontaneous combustion or from sparks from the engine, are quite numerous, consequently the latest types of coal pockets are now built of reinforced concrete, or are of steel construction. The gases, however, from the engine are likely to deteriorate steel structures, whereas reinforced concrete repels any action of the flue gases from the engine.

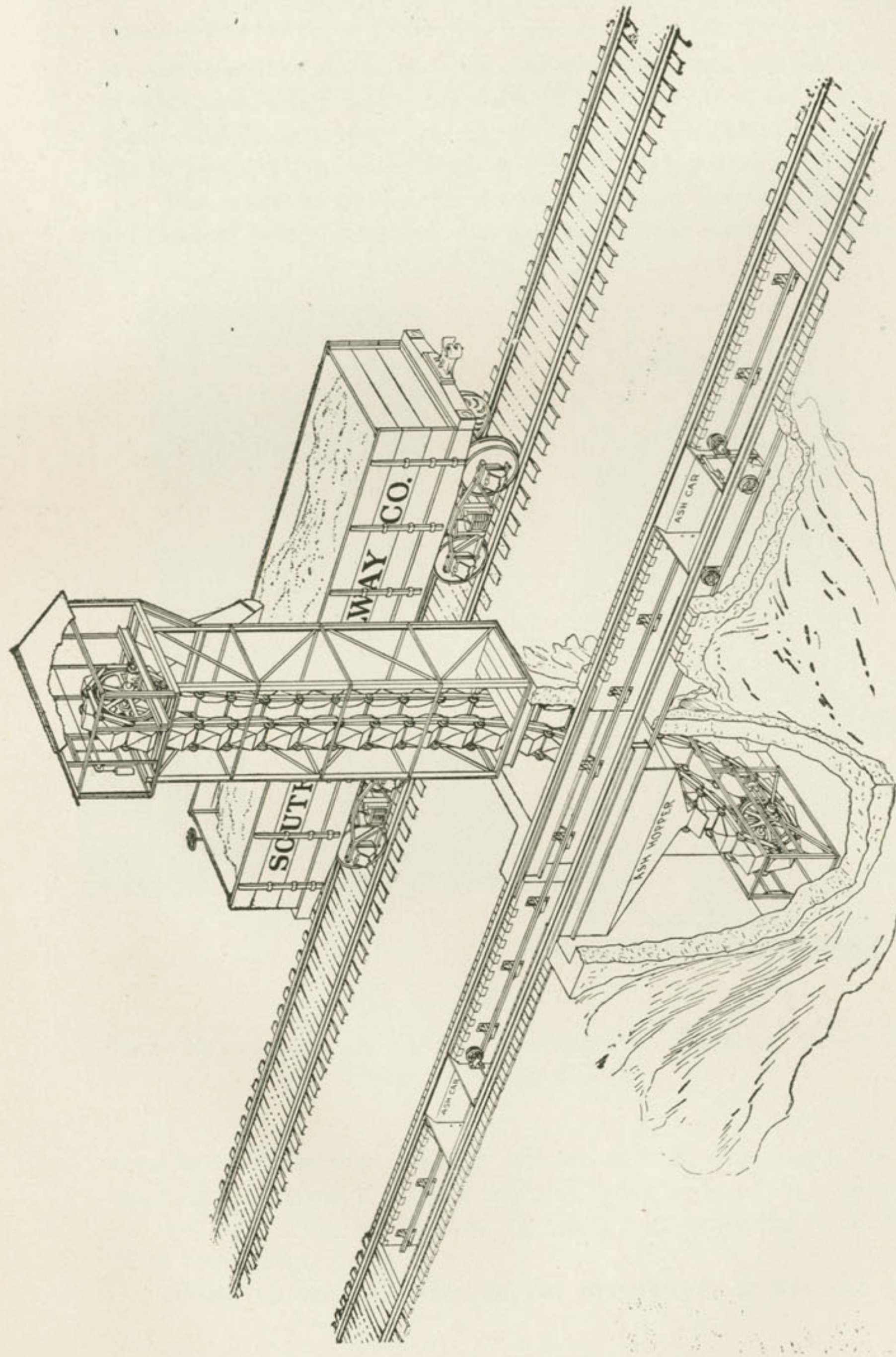
Weighing Coal for Locomotives. In order to prevent the wasteful and extravagant consumption of coal, many roads keep an accurate record of the quantity consumed by each locomotive. Unquestionably the greatest gains which may be made in fuel economy are in its use on the locomotive. The enginemen, however, cannot be watched closely and spurred on to better efforts unless a careful check is kept on the coal consumption and on those things which affect it. This cannot be done unless some means are provided for measuring the coal issued to each engine with a fair degree of accuracy. Under proper supervision there seems to be little question but that the average fireman could save one scoopful of coal in every ten, and he would be more likely to do it if the amount of coal that is used each trip is known and this amount checked up against other engines which make the same run.

In other cases, the uniting of different roads for terminal purposes necessitates the weighing of all coal delivered as a basis on which to proportion charges.

Methods of Weighing Coal. There are several methods by which the coal delivered to the locomotive tenders may be measured with more or less accuracy.

Jib Crane and Bucket System. The simplest method of measuring the coal is the use of the jib crane and bucket system, or where "buggies" are used. The average weight of coal which one of these buckets or buggies will hold can easily be determined, and care can be taken to see that they are loaded uniformly each time. A large percentage of coaling stations where the coal is weighed belong to this type. The practice of weighing coal by this method, as practiced by the Nashville, Chattanooga & St. Louis Railway, is as follows:

Two standard sizes of buggies holding two and three tons of run of mine coal each are in use. It is the duty of the foreman at each chute to see that they are filled to capacity, and a report is made to the fuel inspector each day as to the initial and number of the car from which each buggy is loaded, and the number of the engine to which it is delivered. The fuel inspec-



MODERN METHOD OF HANDLING ASHES
(Link-Belt Engineering Company)

a run, a man shovels the coal down from the sides and back of the tank, levels it up and marks on a coal ticket the "pounds on arrival." To this is added the amount of coal taken. It is thus possible to determine with a close degree of accuracy the amount of coal used on each trip, and with very little extra expense.

Trestle Measuring Type. Another of the older types of coaling stations which allows the coal to be measured is the low trestle type with different size pockets into which the coal is shoveled from the cars. This type of station does not permit the use of self-clearing cars and is becoming obsolete, but where it is in use the coal can be measured quite accurately, if the pockets are properly calibrated.

Overhead Pocket Type. With the large overhead storage pockets the problem becomes a more difficult one. The scheme has been tried of suspending the entire pocket and introducing a weighing dynamometer; but it is of course necessary to have the pocket hang plumb in order to get accurate results; a wind or an eccentric loading interferes with this.

Auxiliary Weighing Pocket. An arrangement which is being used successfully by several roads is to have an auxiliary pocket underneath the storage pocket, as shown in Fig. 3. A simple scale arrangement is used for weighing this auxiliary pocket. Accurate results are attained, and it is said to be inexpensive to maintain. The weighing device is generally a recording beam scale, which automatically registers the exact weight of each draft of coal delivered, thus preventing errors by careless and incompetent weighers. When this arrangement is used the coal to be weighed is carried in pockets holding from 10 to 90 tons, each mounted on a recording beam scale. When coal is to be taken out the scale beam is first balanced by a sliding balance weight, the coal is then drawn and the beam again balanced; this time by the recording weight, after which the operator merely presses the lever and receives a card upon which the exact weight of coal delivered is printed in plain figures. The operator then notes upon the card the number of the engine supplied and turns it over to the proper officer.

Cost of Handling Coal. While the actual cost of handling coal in any case depends largely on local conditions, it may be said in general that when properly designed apparatus is employed the labor cost should not exceed one cent per ton of coal, and in large coaling stations it is often less. The cost of handling coal by a properly designed mechanical station is from 60 to 80 per cent less than by the old method of unloading on trestles and delivering coal to tenders in barrows. Not only does the modern coaling station materially reduce the expense of operation, but by assuring the rapid and systematical handling of locomotives it exerts an influence on the movement of railway traffic, the importance of which is appreciated by railway managements.

REVIEW QUESTIONS.

LOCOMOTIVE COALING STATIONS.

1. Name some of the advantages of a coal handling apparatus over the method of hand coaling.

2. Name five necessary requirements of a locomotive coaling plant.

3. How is the best way to determine what grade of fuel to use on a locomotive?

4. Is it better to burn a cheap coal or an expensive coal? What determines which to use?

5. Describe the method of coaling from cars with a jib crane.

6. Describe the trestle type of coal handling apparatus.

7. What are the disadvantages of the trestle type?

8. When can the locomotive crane type be used to advantage?

9. What are some of the advantages of the link-belt type of coal handling apparatus?

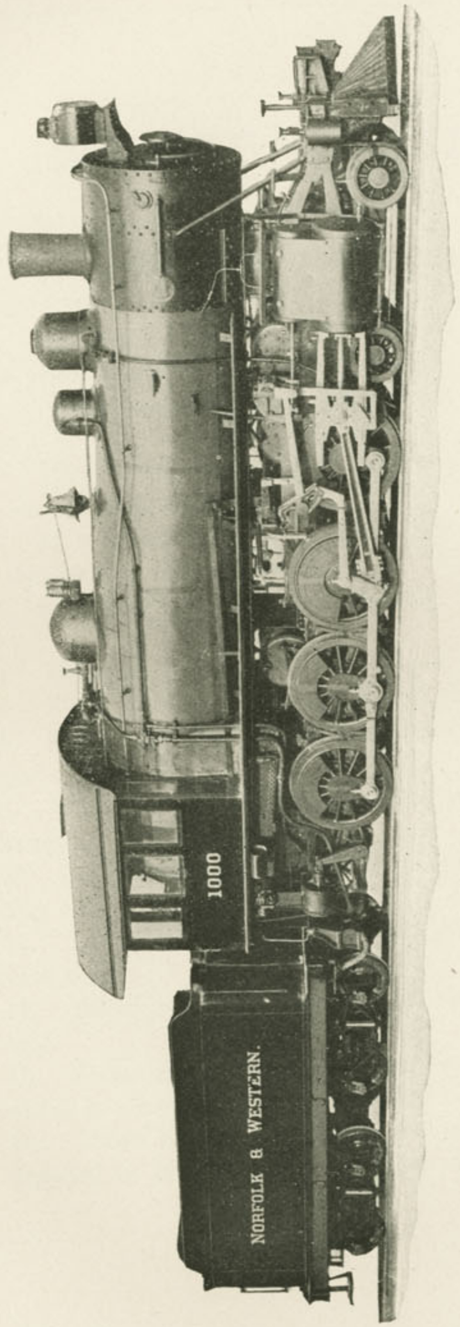
10. Name some precautions which are necessary when handling coal.

11. Describe one method of handling coal and cinders at the same time.

12. What is the advantage of weighing coal for locomotives?

13. Name three different types of coal weighing apparatus, and which is considered to be the best?

14. About how much should the labor cost be per ton of coal handled in large locomotive tender coaling stations?



TWELVE-WHEEL TYPE OF LOCOMOTIVE USED FOR HEAVY FREIGHT SERVICE ON THE NORFOLK & WESTERN RAILROAD
(Baldwin Locomotive Works)

Engine Breakdowns and Their Remedy.

One of the most important matters in the operation of a railroad is to prevent the engine from breaking down; or, if it does break down, to be able to remedy the trouble as quickly as possible. Engine failures, therefore, probably receive more attention than any other one thing in connection with the operation of a railroad, because, if the engine stops, the revenue of the road stops, and many other things attendant thereon suffer. Delays to traffic will occur as long as railroads are operated; but with constant care and the proper attention many of these delays may be either entirely eliminated or greatly reduced.

In order that the mechanical department of a railroad be kept in touch with each engine failure, it is recommended that each road use some systematic course of having each engine failure recorded. For instance, a telegraphic report, to be followed by a copy by mail, of all engine failures should be furnished to the heads of all the departments each morning, and the roundhouse foreman should have complete information of all failures, so that a complete inspection can be made immediately on the arrival of the engine at the terminal.

To further facilitate the mechanical department in decreasing the number of breakdowns, the failures of the engines may be separated on the daily reports into the following general heads:

Air,	Injectors,
Blow-off Cocks,	Oil Burners,
Hot Bearings,	Foaming,
Grates,	Leaking,
Machinery,	Not Steaming, etc.

From these reports all the failures occurring on each operating division may be shown in a monthly report, in which all failures are itemized as follows:

HOT BEARINGS.	MACHINERY.
Driving Boxes,	Piston Loose,
Engine Trucks,	Piston Bent,
Tender Trucks,	Piston Gland Broken,
Eccentrics,	Piston Heads Broken,
Crank Pins, etc.	Piston Follower Broken, etc.

By such a system of tabulation any unusual number of failures due to any one of the foregoing troubles may be readily discovered and such action taken as may be necessary for improvement.

A rigid inspection on the arrival and departure of an engine at a terminal by both the engineer and roundhouse man, and the constant attention of the enginemen while on the road, will serve to improve the service of a locomotive, and with such corrections of imperfections in design as may be determined from the reports of failures, is all that those in immediate charge can accomplish, though the care of an engine both on the road and at the terminal should occupy the attention of all in the operating department.

Since it is very important that the engine be kept in operation under all conditions when out on the road, and since all machinery will break down, it is necessary that the engineer should know what to do in cases of emergency, so as to be able to bring the engine and its train into the desired terminal in the least possible time. While it is often the unexpected that happens, yet the following breakdowns are the most usual ones, so that if the engineer understands thoroughly how to remedy them, he will be in a position to meet almost every condition which may arise.

Besides actual breakdowns, there are a large number of engine faults that should be reported by the engineer, such as badly fitted brasses, loose pistons, etc., and in describing the engine trouble the exact location and side should be given.

Some roads have adopted a method which prevents mistake, by numbering the wheels, beginning at the forward engine truck wheel on right side, going around the tender, and ending with engine truck wheel on left side, in consecutive number, as wheel No. 1, No. 2, No. 3, etc. On an 8-wheel engine the left forward would be No. 16, according to this system.

Causes of Pounding. Some of the various causes for pounds are wedges not properly adjusted, loose pedestal braces, lost motion between guides and crossheads, badly fitting driving brasses, improper keying of rod brasses, engine and rods out of tram, loose piston on rod or loose follower bolts.

A pound in driving box wedges or rod brasses may be located by placing the right main pin on the upper forward eighth, which brings the left main pin to the upper back eighth. Then by blocking the drivers, giving the cylinders a little steam and reversing the engine under pressure, both sides can be tested at the same time.

When Repair Work Should Be Reported. Crossheads or guides may be reported to be lined when there is sufficient lost motion between crosshead and guides to cause a jumping motion when the pin is leaving either dead center and the crosshead is beginning the return stroke.

Driving box wedges may be reported to be lined when the wedge has been forced up as high as it can go and lost motion appears between wedge and box.

Rod brasses should be reported to be filled when there is sufficient lost motion to cause pounding.

Rod brasses should be reported to be lined when the key is down to a point where it cannot be forced down further to prevent brass working in strap.

Lost motion between engine and tender should be taken up when there is one-quarter inch or more lost motion between engine and tender, causing an undue strain on the drawbar by the forward and backward lurching of the engine while in motion, or the forward lurch in starting. It also causes severe strain on draft rods.

Engine Disabled on the Road. First, protect the train front and rear by flags the prescribed distance. Make such temporary repairs as are necessary to get the train to the next siding, in order to prevent blocking the main line. When on the siding make all the repairs practicable with the tools at hand. If the breakdown is of such a nature as to prevent the possibility of making even temporary repairs, so as to clear the main lines, arrange to notify the nearest telegraph office of your location and ask for assistance.

Derangement of Valve Gear. If an engine suddenly begins to go "lame," it indicates that one of four things has happened. Either a dry valve, a slipped eccentric, a loose strap bolt, or an eccentric blade is loose and has slipped. If, after stopping and looking it over, it is found that none of the three last mentioned things is the cause, and the engine is again started, and the exhaust sounds square, it shows that one of the valves was dry, and that when she was shut off the oil remaining in the oil pipe was drawn into the valve chest by the vacuum. Sometimes the exhaust will in time wear a hole in the petticoat pipe, and this will cause the exhaust to sound "lame," or the tumbling shaft may be sprung, which will cause a longer cut-off on one side than on the other. In this case there will be two heavy blasts on one side and two light ones on the other side.

Slipped Eccentric. Place one side of the engine on the center as near as possible; either center will do. Put the reverse lever in extreme forward motion, and then, with a lead pencil or the point of a knife blade, make a mark on the valve stem at the gland. Now, have the fireman put the lever in extreme backward motion, and if neither one of the eccentrics on that side has slipped, the mark will come back to very near the same position it was in when the lever was in forward motion. If it does not come within a quarter of an inch of its first position, the trouble is on that side, and if the original marks are on the eccentric and driver axle, the eccentric may be easily reset; but if there are no marks, the mark made on the valve stem at the gland will serve as a temporary guide in resetting the slipped eccentric.

There are several ways of getting very close to the center. Move the engine till the center of main axle, main crank-pin and crosshead pin are on the same exact line on that side, or till the centers of axles and centers of crank-pins are on the same horizontal line, or till a straight-edge on top and bottom of the main rod strap comes the same distance each side of the center of the main axle. Or, go to the other side of engine, place it on the quarter, measure from the center of the main axle to the center of main crank pin, move the engine if necessary till the distances are the same; the engine will be on the quarter on that side and the center on the other.

Disconnecting One Side. This necessarily implies that the engine is to continue its trip. Remove the main rod on one side, and place the liners and brasses back in the straps. Secure the crosshead near the back end of the guides with a crosshead clamp, or with hard wooden blocks, securing the blocks with a rope so they cannot work out. Don't move the crosshead clear back to the striking point, as the cylinder packing rings may get down into the port or counterbore. Remove the valve rod and secure the valve stem with a valve stem clamp, set the valve central upon its seat, and cramp the valve stem by tightening the gland on one side. Most engines that use metallic packing are supplied with a valve-stem clamp made to hold the valve central upon its seat; but the valve can easily be set to cover the ports by opening the cylinder cocks and giving the engine a little steam. Then adjust the valve stem until steam is entirely shut off from both cylinder cocks. Do not remove the eccentric straps or side rods unless it is necessary. Whenever the eccentric straps are removed on one side, the top of the link should be tied to the short arm of the tumbling shaft to keep it from tipping over, which would prevent reversing the engine. If it is necessary to take one side rod down, remove the one directly opposite to it. If this cannot be done, then remove all the side rods. Do not remove the eccentric blades, leaving the straps on the eccentrics, if they clear everything in all positions; otherwise they might punch holes in the fire-box. In removing the forward section of side rods on some makes of 10-wheel, Mogul or Consolidation engines, care must be exercised where blocking of crosshead back is necessary. Very often the crank-pin will interfere with the piston rod key in crosshead. When this is the case, cut off the key flush with the crosshead or block the crosshead forward.

Disconnecting Both Sides. This implies that the engine is dead and must be towed in. Remove both main rods and both valve rods; but it will not be necessary to block either if the crank-pins clear the crossheads. Do not remove the side rods or eccentric straps unless it is necessary; and when it is considered necessary be sure to take the precautions previously explained.

In freezing weather, if the fire is down, all water should be drained out of the injectors, pumps, feed and branch pipes. If there are any frost plugs, slack the joints and let the water out. If there is danger of the water freezing in the boiler, run it out of both boiler and tank. See that all oil cups are well filled before starting. Almost all roads are very strict regarding the speed of dead or disconnected engines, as the engine is not then counterbalanced perfectly, and is therefore very injurious to the track. Some of the best roads limit the speed of all heavy engines which are disconnected on one or both sides, or which have the side rods removed, or dead engines hauled in a train, to twenty miles per hour.

Broken Main Rod or Strap. Remove the broken parts, block crosshead back to within one-half of clearance to keep the cylinder packing out of the counterbore, disconnect cylinder-cock rod on disabled side and block cocks open. Shift the valve in the same direction as piston, if it is a slide valve or outside-admission piston valve, and in the opposite direction if it is an inside-admission piston valve. An easy way to remember and distinguish a direct from an indirect motion is in the position of the rocker arm. With the indirect one arm is always above and the other below the rocker box; with the direct both arms are either above or below the rocker box. In moving the valve give it just enough opening to show steam at the cylinder cock, which will take the pressure off the blocking.

Broken Side Rod or Strap. Remove the broken rod and the parallel rod directly opposite to it. If it is a ten-wheeled engine, and this cannot be done, remove all the side rods. If a front or back rod or strap on a twelve-wheeled engine, remove the broken rod and the one directly opposite to it, if this can be done, and leave the others up.

Broken Cylinder Heads. If the back head is broken, disconnect the engine on broken side. If it is necessary to remove the guides and broken head, then remove the piston also.

If the front head is broken, disconnect that side of the engine.

It may also sometimes be possible to block the head with heavy blocking, using a screw jack placed against the pilot timber; but the time taken to do this would often counterbalance the advantages gained.

Broken Steam Chest or Cover. When the break is not a bad one, wedging between the chest and bolts is sometimes successful; but where the break is a bad one remove the cover, block the supply ports, which on modern engines are at each end of the cylinder, with blocking of sufficient thickness to be held down by cover, disconnect the valve stem only, block the cylinder cocks open, and proceed on one side. The same method applies to a broken cover.

Metallic Packing Givng Out On the Road. Take off the stuffing-box or packing case, and if any of the old packing is left, leave a ring of it in the cone or cup; then make, out of wicking or other available substance, a ring of packing sufficiently large to fill the balance of the space in the cone, after which push the cone back against the "follower" on the end of the spring, put on the stuffing-box and go along.

Broken Piston. If the piston is broken and the piston rod bent, remove both, disconnect the valve stem and cover ports.

Broken Piston Rod. If the broken rod has taken the cylinder head along with it, disconnect the valve rod and cover ports.

Broken Crank-pin. With a broken main crank-pin, on any class of engine, take down all side rods, and be sure that the crank-pin on the forward wheel does not interfere with the crosshead in blocking the latter. With the back crank-pin on a Consolidation or a ten-wheel engine, proceed as with a broken side rod; but with the crank-pin of an intermediate, otherwise known as driver No. 2, take down all side rods and run in light with the main rods up. Remember that taking down one section and not the other on the opposite side is dangerous. There is nothing to pull the wheel on the good side off the dead center. In only one case is this permissible—when the eccentrics are on the first or leading, and the main rod on the second or main drivers. In this instance, if the forward section, with a solid end, breaks, the other side is to be left up, so as to control the valve motion on the good side; but the valve gear on the crippled side must be disconnected.

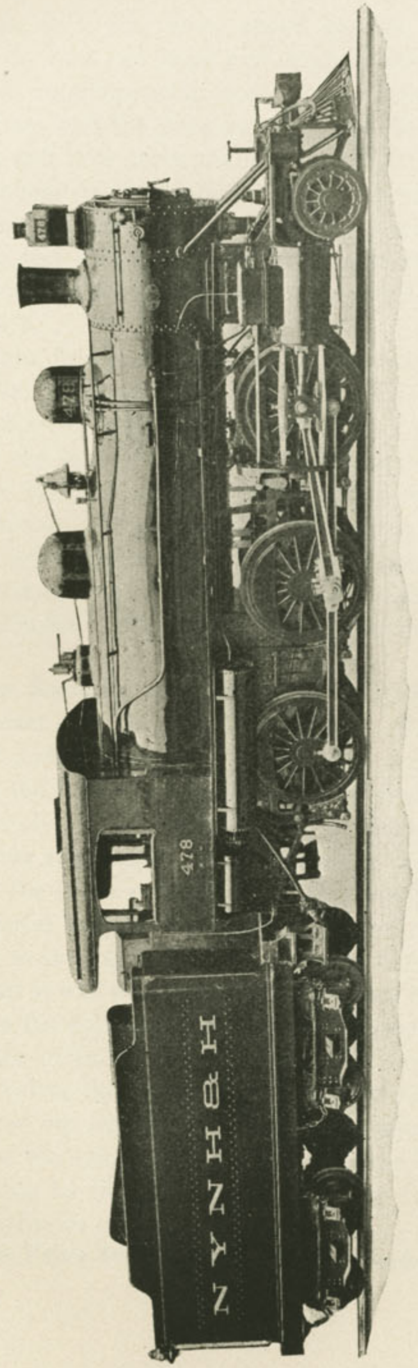
Broken Crosshead. If the break is with a four-bar guide or a

Laird guide with you, block ahead and let the main rod rest in yoke; but the butt end brass and strap must come down, otherwise the rod will interfere with main pin. If the crosshead is of the alligator type, and the yoke secured near the middle of the guide, block back and take down the main rod. It is always a good plan to allow enough port opening, in blocking valve central, to admit a little steam against the piston in the direction of the blocking. Remember also that an outside admission valve is pushed in the same direction as the piston, and an inside admission in the opposite direction.

A slight break, such as a gib or plate, may sometimes be clamped, but be careful that the clamp does not strike the guide block at extreme travel of the crosshead. If it is a bad break, disconnect the broken side. If the piston is not broken, push it against the forward cylinder head, and then block the crosshead in that position. If the crosshead is broken so that the crosshead cannot be blocked, the safest way is to remove the piston. If it cannot be taken out, set the valve so as to admit steam to the back end of cylinder only, and clamp valve stem securely in this position.

Broken Eccentric, Eccentric Strap or Blade, Broken Valve Rod, Broken Rocker Arm, Broken Link or Pin. Take off both eccentric straps and rods on that side, fasten the top end of the link by tying it to the link hanger and tumbling shaft arm so that it cannot tumble over and interfere with reversing the engine. Place valve to cover steam ports, clamp the valve stem so it cannot move, disconnect the main rod and block the crosshead. With a heavy engine a better way is to take off the eccentric straps; tie the top of the link to the top end of link hanger; block the valve in such a position that it will admit a very little steam to the back steam port to lubricate the cylinder; have the lubricator feeding to that side. Take out the cylinder cocks, or block them open on that side and any relief valves there may be in the forward cylinder head, leave the main rod up and proceed. If the engine gets caught on the center, close the cylinder cock opening in the back end of cylinder; steam leaking by the valve will soon move it off the center; then open this cylinder cock and go ahead.

Broken Valve Seat. When a seat is broken the engine usually



MOGUL TYPE LOCOMOTIVE USED FOR FREIGHT SERVICE—NEW YORK, NEW HAVEN & HARTFORD R. R.
(Baldwin Locomotive Works)

blows through on that side, how badly depends on what is broken and whether the valve is also broken. If the bridge or partition between the steam port to one end of the cylinder and the exhaust port is broken, when the valve uncovers that steam port live steam can get to the exhaust the full size of the broken place. If it is a false valve seat, it may be broken so badly that steam will blow through it in any position of the valve. When a valve seat breaks it usually catches the edge of the valve and springs the valve rod, the rocker arm or the eccentric blade, in which case an inspection of the engine should show the damaged parts that are outside the steam chest. If the valve catches so the engine cannot be reversed, it is an easy matter to locate the trouble by holding a hand on the valve rod while the lever is moved; if that side catches, it is soon felt.

After locating the trouble, take up steam chest cover and block over the openings to keep the steam from passing through. A board covering both steam ports and the exhaust port will do this; in the case of a false seat take out all the pieces, if they cannot be fitted steam-tight. Usually the valve will have to be left out and a block fitted in between the board and steam chest cover to hold the board from rising up when engine is shut off and drifting. In the case of a balanced valve, the top of the valve comes so close to the pressure plate that the valve will not go in again with a board under it, nor can the broken false seat be taken out and the balanced slide valve be dropped on the cylinder casting, unless the top of valve is also blocked to keep steam out of the exhaust cavity of the valve. Some false seats are fastened to the cylinder casting by tap bolts going into the lands and bridges between the ports, in which case the broken seat cannot be taken out, but must be covered so that steam cannot get by it. After locating the trouble, disconnect the engine on that side, taking down the main rod and blocking the crosshead. It is usually necessary to take off both eccentric straps and rods, as the bottom rocker arm may be bent out so the link will be cramped on the block. If, after disconnecting, the reverse lever cannot move both links easily, uncouple the link hanger on the disabled side from the tumbling shaft arm.

Broken Valve. With a valve badly broken, remove the valve and block on the top of steam ports with sheet iron and wood at your command. With a balance valve, where the space between the valve and valve table is from 1-16 in. to 1-8 in., use sheet iron on the face of valve and blocking at either end. Take out cylinder cock valves and leave main rod up. For a broken piston valve, if the break is not a bad one, shift valve enough to stop the blow, and clamp valve stem at one end and extension rod at the other end. Where there is no extension rod, block between valve and forward head.

Broken Release Valve. When a release valve is broken it does not imply that the valve is entirely useless. Remove release valve casing from chest and insert a wooden plug in casing and screw it back again. If there is a spare washout plug on the engine, remove the casing and screw the plug in instead.

Broken Valve Yoke. A valve yoke usually breaks off at the neck of the valve stem. It can be readily discovered in the exhaust by a tremendous blow. If the valve is pushed far enough ahead, it will blow; if not, it is often mistaken for a slipped eccentric (examine the eccentrics first). It may be discovered in this way: Place the crank-pin on the top or bottom quarter and reverse the engine; if the steam still continues to come out of the stack cylinder cock it is usually the yoke. A great diversity of The old and safest way is to raise the chest cover and block the opinion exists regarding the best remedy for this kind of a break. rod and block the crosshead at the back end. But this remedy valve central, replace the cover, remove the valve rod and main requires much time and labor, and time is a very important consideration on the road, and there appears to be no mechanical objections to the other methods, providing the crosshead is securely fastened. Disconnect the valve rod and push the valve clear ahead, remove the stem if it would blow out, and use a gasket back of the gland, or hold the valve stem intact with valve stem clamp. Block the crosshead at the front end, and proceed; the pressure will hold the valve forward, and if it should move it can do no harm providing the crosshead is securely blocked. Another way is to remove the release valve, push the valve clear back, fit a block into the release valve long enough to hold the valve back, then block crosshead at back end. Still another way is to

push the valve stem forward and clamp it by cocking the gland, then block crosshead at the front end. If the yoke is only broken at one side of the valve, it will only affect one exhaust. When the yoke pushes the valve forward the exhaust will sound all right, but when it pulls the valve back the engine will be lame.

Broken Guides, Blocks or Bolts. If any of the bolts break, try to replace them. See that all nuts are tight, or they may be the cause of springing the piston-rod. If a guide is broken badly, disconnect one side.

Broken Guide Yoke. If a yoke is bent or broken and will not hold the guides secure, disconnect one side.

Broken Driving Brass. Run the wheel upon a frog or wedge and block up between the frame and spring saddle, to take the weight as much as possible off the box.

With an engine having underhung springs there is no saddle to block under, and in a case of this kind place a jack under the equalizers nearest to the broken brass, then block the other end between the frame and the equalizer and remove the spring under the broken brass if possible.

Broken Driving Axle. This occurs usually close to the wheel and outside of the driving box. If it is a broken main driving axle, all rods on the disabled side and all side rods on the good side must come down. With any other driving axle, only such rods should come down as would give trouble to the rest of the rods.

To block up the axle on the broken side, remove the cellar and put a wooden block between the axle and the binder brace. If a hydraulic or screw-jack is handy, raise the axle and driving box, if it has an overhung spring, and block under the spring saddle above the frame to take the weight off the driving box. Use sponging on the sides of the blocking under axle, or, better still, hot main-pin grease.

Broken Rocker Box or Arm. With the bottom rocker arm broken there is more or less danger of catching the link or blade on the rocker box, if the link motion is considerably worn. Take no chances, but take down both eccentric straps and blades and cover ports. If the top arm is broken, remove broken part and cover ports.

With a direct-motion valve gear, remove transmitting bar and broken arm and cover ports. By transmitting bar is meant the rod that conveys the motion from the link to the rocker arm. For a broken rocker box, or sheared bolts, if no repairs are possible or no bolts at hand of nearly the same diameter as the old ones, take down both eccentric straps and secure the link to link lifter, and remove rocker box if bolts are sheared.

Broken Link Lifter. Place the lever in quadrant at a point where you can comfortably start your train. Cut a block of wood to fit between the top of link block and link, also one to fit between bottom of link block and link. Fasten them securely. Blocking for the forward motion, never drop the lever below the point of cut-off selected, as the lifting arm on tumbling shaft may interfere with link. You can cut the lever back toward the center without danger, and work steam expansively on the good side, but this will give you two light and two heavy exhausts. Don't attempt to reverse your engine without first removing the blocking from below the link block and placing it on the top of link block.

Sprung Link. On certain classes of engines with a 4-wheel truck and the lever in the extreme forward notch, the links are in such close proximity to the truck that invariably from any cause of derailment the links are generally badly damaged or sprung. With the solid link you have no alternative but to disconnect the valve gear. With the sectional link, unless too badly damaged, slack off the nuts on top and bottom of link bolts, partly withdraw the bolts and insert a washer of sufficient thickness to allow the free movement of link block in the link when reversing the lever. Tighten bolts again and you are free to go on with your train without disconnecting.

Broken Reach Rod, or Arm of Tumbling Shaft. Put a very short block in the link on top of link block and a long one in the bottom end of link so that side will work full stroke. Do not block both links, only one. When the engine is moving, with both link hangers in position, as they should be with a broken reach rod, at one point of the stroke one link tends to slip up on its block, while the other link is slipping down. If both links are blocked solid top and bottom, the tumbling shaft must bend or spring. To reverse the engine, put the long block in top of link.

Broken Equalizers. Raise the engine the same as for a broken spring or hanger when possible to do so. If it is an equalizer on a standard eight-wheeled engine, block on top of one box and block up the loose end of the equalizer, when possible, the same as for a broken spring or hanger; if it cannot be used, remove the equalizer and block on top of both boxes. If an equalizer on a ten-wheeled engine, block on top of the forward and main boxes, and block up forward end of back equalizer. If it is the cross equalizer on a Mogul, block on top of both foward boxes and block on top of the back end of the long intermediate equalizer that goes to the truck. If the intermediate equalizer breaks, block between the boiler and the cross equalizer. If it is the cross equalizer on a four-wheeled pony, block on top of both forward boxes. When this equalizer is below or between the frames it is sometimes possible to block between the hangers and the frame. If a small equalizer that rides the back box, block on top of the back box and chain up the back end of the bottom equalizer. If it is a truck equalizer block on top of truck boxes between the box and truck frame.

Broken Equalizer Stands. If the stand breaks, then use the same remedy as for a broken equalizer, but if only the bolts break, find some old bolts to replace them, or take bolts off some other part of the engine that will fit, and the loss of which will not impair the working of the other parts.

Broken Engine Truck Hanger or Center Casting. If a four-wheel engine truck, block over the equalizers and under the top bar of engine truck frame close to band of spring, high enough so the engine will ride level with the other side. With a Mogul, block over the truck box. If the engine truck center casting breaks on a standard engine, block across under truck frame and center casting and over equalizers, from one side to the other; a couple of pieces of rail, 4½ or 5 ft. long, may come handy for this purpose. Or, put a solid block under the engine frame next to the saddle and on top of the truck frame on each side. This plan will give the use of the engine truck springs, although it does not always hold the center casting up against the male casting under the smoke arch, so the engine will track straight.

In case it becomes necessary to remove an engine truck entirely from a Mogul or Combination engine, proceed as follows:

Block between the cross equalizer and bottom of the boiler; with the engine in this condition, she should be run carefully, as there is quite an additional load on the front driving boxes.

Broken Engine Truck Wheel or Axle. If a piece is broken out of the wheel, it can be skidded to next side track by laying a tie in front of the pair of wheels. If an axle is broken or a wheel is broken off outside of the box, that corner of the engine truck may be chained up to the engine frame, being careful to chain so as to crowd the good wheel against the rail, and put a block between the top of the engine truck and bottom of the engine frame, on the other end of the same side of truck, in order to put the weight on that part of the truck. If it is a broken tire, jack up the front end of the engine to take the weight off the truck. Take out the cellar and block with a V-shaped block of wood between the axle and pedestal brace. Jack up the truck frame high enough to allow broken wheel to clear the rail and secure the truck to the engine frame with a chain.

Disconnected or Broken Throttle Rod. The seriousness of this accident depends entirely upon the nature of the break. If the throttle is open and cannot be closed, reduce the steam pressure to a point where the engine can be controlled with the reverse lever. It is a good plan to have some cars connected to the engine, in order to get the benefit of the brakes in case an attempt is made to run the engine in with a broken throttle. Sometimes what is considered to be a disconnected throttle valve proves to be a cocked valve. If the rod connections are badly worn and a full throttle opening given, a cocked valve often results, and is mistaken for a disconnected throttle. If the throttle is closed and will not open, it is very likely that the rod is disconnected inside the boiler, in which case the only remedy is to kill the fire and prepare to be towed in, unless the company requires the engineers to make repairs.

Broken Back Spring on Consolidation Engine. Run the driver up on a wedge; pry up the back end of the equalizer and block between it and rail of frame; then run back driver off the wedge and the next driver up on it, and block between the back driving box and the frame.

Broken Front or Back Section of a Side Rod on a Consolidation Engine. A Consolidation engine has a knuckle joint between the first and second, and third and fourth pairs of drivers. In case of a section on either end breaking, remove the broken parts and the corresponding section on the other side. Be sure that the forward crank-pin will clear the crosshead in all positions before moving the engine.

Broken or Loose Tire on Standard Eight-wheel Engine. If a main tire breaks or becomes loose, raise the wheel center up off the rail a little higher than the thickness of the tire, to allow for the engine settling when blocked up; take out the oil cellar so the journal will not get cut on the edges of the cellar; put a solid block of wood between the pedestal brace and journal to hold the wheel center up clear of the rail; block up over the back driving box so the engine cannot settle or get down so as to allow the wheel center brace to strike the rail. It will take a good deal of strain off the pedestal brace to put a block under the spring saddle on top of the frame. Taking out this driving spring makes a sure job. Take off all other broken or disabled parts. If the rods are in good order, leave them up. If a back tire breaks, block up in the same manner as for a main tire, except that blocking comes next to the other journals and boxes.

Broken Tire of a Ten-wheel Engine. Run the wheel upon a wedge so as to clear the rail under all conditions. Remove the oil cellar and fit a block in its place; then place another block between bottom of box and pedestal binder. Also block under the equalizers nearest the disabled wheel to take the weight off the journal.

Broken Tender Wheel or Axle. Find a piece of a rail the proper length, or a cross tie will answer. Place it across the top of the tank directly over the broken pair of wheels. Block under the rail or tie to protect the flange on the top of the tender. Jack up the broken pair of wheels to clear the rail, and while in this position chain the truck to the rail above the tank on both sides.

Broken Frame. For a broken frame ahead of main driver disconnect the valve stem on disabled side, cover ports and leave up main rod. Bring your engine in light with the good side. If the break is behind the main driver, take down side rods on rear section only, if a Consolidation. With a Mogul type and the knuckle pin on forward section of side rod, take down all side rods.

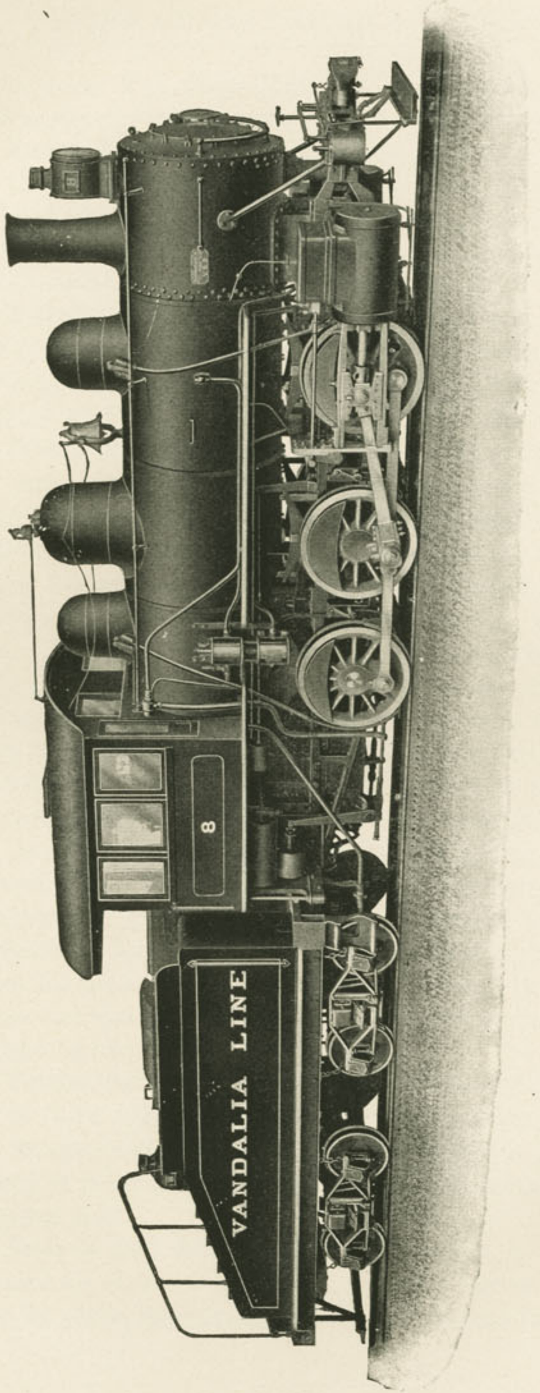
Broken Draw Bar. If the engine has safety chains, they will hold the tank, but not always a heavy train. If the engine is not equipped with safety chains, then secure a chain from the tank box or caboose, and chain the tank to the deck. Safety chains should not have more than four-inch slack.

Broken Wedge Belt. In this case it is sometimes possible to screw the nut half-way onto each part of the broken bolt and thereby hold it up in place. If this cannot be done, then with a wire try to fasten a nut under the wedge to hold it up.

Broken Driving Spring or Hanger. If the engine is raised with jacks, block up the end of the equalizer that has been connected to broken part, so that it is a little higher than it was before, to allow for settling. It is customary also to block up between driving box and frame at the box where spring is broken. If it is the forward box, it puts the load on that box, which may be too much. It is better to block up over a back driving box, no matter which spring is broken, as the weight is carried there the best. If the engine is raised by running up on blocks or wedges, put block on top of the box that is under broken spring first, if possible, then run that wheel up on a wedge until engine is raised so that the equalizer can be blocked up level again; then put block over box, also, to carry what weight of engine the spring still at work on that side would not hold up; take out the broken spring or hanger if necessary. If equalizer is under frame and boxes, block under end that will hold it in proper place. If the reach rod is pinched, so that the reverse lever cannot move the links, it may be necessary to take out the pin holding the reach rod to the tumbling shaft arm and handle the links otherwise.

Broken Frame Between Main Driver and Cylinder. The safest plan is to be towed in dead. The other alternative is to disconnect the disabled side and bring the engine in light, because an attempt to bring in part of the train might damage the previously uninjured side.

Loose or Lost Cylinder Key. If the key is loose and can be shimmed up, it is safe to go on. If key is lost and nothing available in its place, disconnect that side to prevent further damage.



SIX WHEEL SWITCHING o-6-o TYPE LOCOMOTIVE
(American Locomotive Company)

Frames Broken Back of Main Drivers. Take down side rods on both sides back of main driver and proceed.

Water Glass Out of Order. If the water line in the glass is not in sight, and moves up and down when the engine is in motion, it indicates that the water glass valves are either stopped up or closed, and require immediate attention.

The blow-out cock at the bottom should be opened. If the water line shows in the glass, and then suddenly rises out of sight when the blow-out cock is closed, it indicates that the water level in the boiler is higher than the top end of the glass. If only steam or a mixture of steam and water passes out through the blow-out cock, it is evidence that the water in the boiler is too low, and if no water shows in the glass when blow-out cock is closed, the fire should be deadened at once.

If gauge cocks and lower water glass valve are stopped up, get engine and train off the main line onto a siding as soon as possible. Deaden or dump the fire, and report conditions. No engine should be worked in that condition.

If an Engine Works Water. Close the throttle a little at a time, until the water ceases to pass over into the cylinders. If it is foaming, this will stop the trouble in the cylinders, and the water level in the boiler will drop at once. If the boiler is pumped too full, the water level will be above the gauge cocks.

Broken Blow-off Cock, or Hole Broken in the Boiler. Either dump the fire or smother it with wet coal; get steam and water out of the boiler as quickly as possible. If the blow-off cock is broken off, it may be plugged; but if it is blown out, it would be impracticable to plug the opening, and the only method is to treat such a case the same as with a hole knocked in the boiler, viz.: disconnect the engine and be towed in.

In Case the Lubricator Refuses to Work. First, see if the steam valve to the boiler is open, then shut off the water valve from the condenser and open the drip valve in bottom of the oil tank. This will blow the water out of the glasses into the oil tank with some makes of cups, and as soon as the glass is filled up with water they might feed again. Or, shut off steam and water valve and open drip cock, then give engine steam and have steam from steam chest blow through the chokes and clean them out. With the new style of cups having check valves, open the drip from the glass, blow it out clean and refill it with water. Lubricators usually stop feeding because some small openings are stopped up or something is wrong inside the cup.

If an Injector Will Not Work. Be sure the injector gets a full supply of steam. The steam throttle may be only partially open. Some injector steam pipes are coupled to a turret. If the valve between the boiler and the turret is partly closed, the injector may not get a full supply of steam, and will not pick up the water. In this case a full supply of water is passing through the injector, but there is not sufficient steam to force the water into the boiler.

Examine the tank to see how much water there is in it. If plenty there, examine the hose, strainers and supply pipe to see if the injector can get the proper supply of water promptly. Next see if there are any leaks that will let air get into the supply pipe of a lifting injector. Last, see if any foreign substance has got into the injector and choked any of the passages.

If an Injector Will Not Prime. The water may be all out of the tank, or the tank valve disconnected; air may be leaking into the supply pipe, the overflow valve stopped up or choked some; or the jet of steam may not pass exactly through the middle of the tube which exhausts air or starts the flow of the water.

If an Injector Primes Well, and then Loses Its Priming When Steam is Turned On Full. The boiler check valve may be stuck shut so the water cannot get away from the injector, the tubes may be coated with lime so they are too small or not of the proper shape, the tubes may be loose so they are not in line, or the supply of water may not be sufficient to condense all the steam. This may be on account of the feed water being hot.

When the boiler check valve sticks open or allows the boiler pressure to back up to the injector, jar the check case or delivery pipes a little so the check valve will settle into its seat. If it does not seat tight, but leaks back, report its condition on arrival at terminal. Sometimes something will get into the delivery pipe and work under the check valve, holding it open. When the check is ground in, this foreign substance, which may be a part of the injector, will drop back into the delivery pipe and lie there till the injector is worked the next time, when it will get under the valve

and hold it up again. Take off the delivery pipe and clean it out.

Failure of Water Supply in Tender. If the water supply in the tender fails while out on the road away from a water tank, in warm weather, if possible, haul enough water into the tank to get it to a water tank, and then fill up the tank. If in the winter, and there is snow on the ground, shovel snow into the tank and melt it with steam from the boiler. If impossible to get water by the methods explained, draw the fire, disconnect the engine and be towed in.

Broken Whistle Stand. A broken whistle stand means a dead engine. Remove the broken part from the dome. A handy thing to have around an engine is a wash-out plug and several sizes of reducers. In the absence of a wash-out plug, use the reducer in the dome cap, then take the nipple and angle cock off an air-braked car, and insert into the reducer.

Grates Burned Out or Broken. Block up the broken or burnt grates with fish-plates, brick, or anything conveniently at hand, and disconnect the good grate immediately ahead and back of the burnt section, in order to prevent disturbing the other grates when shaking down fire.

Broken Safety Valve Spring. Remove the spring and block between valve and cap, allowing the other valve to do the work.

Burst Flue. Dump the fire and lower the steam pressure as soon as possible, in order to save the water in the boiler, then proceed to plug the flue with an iron plug if one is available. If no iron plug is at hand, use a wooden one, driving it into the flue for some distance. It will not burn, because no air can get at it. By putting on the blower slightly and putting a plank down on the grates, a man can often succeed in plugging a flue before the pressure is all out of the boiler. Care should be exercised in driving an iron plug not to drive too hard, as there is danger of cracking the flue sheet. In freezing weather open blow-off cocks, let out all of the water, take down hose connections between engine and tender, and be prepared to be towed in. With the extension front end in general use it is next to impossible to reach a flue without removal of draft plates, so that, generally speaking, the time consumed would not justify repairs on the road.

Leaky Flues. In case of a boiler in which the flues are leaking at the heads, pump the boiler as regularly as possible; have a bright, even fire; use great care that no cold air strikes the flues through the door or through holes in the fire near the flue sheet. Keep an even pressure of steam, as this means a steady temperature in the fire-box. Be very careful in the use of the blower that no cold air is drawn against the flues. This especially applies to the operation of cleaning the fire. Cold air contracts the flues, also the metal of the flue sheet, which causes them to begin leaking at once.

Most injectors have the heater cocks so arranged that they can easily be removed. If bran or sawdust can be had, start the injector first, then take out the heater cock and put a small quantity of the bran through this opening while the injector is working. The current will carry it to the boiler without any difficulty, and will often stop the leak. Too much bran will cause the engine to foam. Gauge and water glass cocks must be opened often, however, to keep them from clogging.

Care and Inspection of Locomotives.

A locomotive should always be inspected after it has finished its run, when there is no fire in the fire-box, so that the grates, smoke-box, chimney and other parts, can be examined. The object of this inspection is to see whether any repairs are needed before the next run, in which case the proper repairs should be made.

Testing Boilers. When inspecting the boiler it should be tested either with cold water, warm water, or steam pressure. In making the cold water test the boiler is filled with cold water, an additional quantity is forced in with a pump so as to raise the pressure to about $1\frac{1}{2}$ times the regular running pressure. When testing with warm water the boiler may be entirely filled with cold water and a fire kindled in the grate. As the temperature rises the pressure will rise, and when the proper pressure is obtained the fire can be withdrawn and the boiler examined for leaks. In some cases steam pressure is used, which, however, is not recommended, because should the boiler not prove strong enough to stand the test there will be an explosion, and since the object of testing a boiler is to prevent an explosion, the test may aggravate the evil it is intended to prevent.

Before old boilers are tested they should be examined carefully inside and outside to see whether they are injuriously corroded. To do this properly the engineer should, if possible, get inside of the boiler and examine the various parts for himself, although it is usual to let the boiler-maker, who is employed for this purpose, make the test.

Examination of Fire-box. The fire-box should be carefully examined to see if there are any indications of leaks, which may be due to cracked plates, defective stay bolts, or defective flues.

Should the tubes be found leaky, they may be made tight by either caulking or by the use of a tube expander. Leaks may be temporarily stopped by introducing some starchy substance mixed with the water, such as bran. The leak, however, should always be corrected as soon as possible after it is found, as it often indicates a dangerous condition of the boiler. A leak about the boiler head may be due to a broken stay, which may be indicated by the bulging of the plate which forms the boiler head. The inside of the boiler must, of course, be kept clean, which may be done either by using the proper kind of feed-water, or, where that is not possible, it should be thoroughly washed out at frequent intervals.

Washing Boilers. When washing out boilers hot water should be used, as it is less likely to injure the boiler in case the boiler is hot. It, of course, involves the expense of heating this water, but this is considered a small matter compared to leaky tubes, which may be caused by the use of cold water when washing out the boiler. The hot water system of washing boilers should be used in districts where there is bad water, especially where water-softening plants are used, as it will increase the life of the fire-box. If, however, the boiler is allowed to cool properly, cold water will remove the scale better than hot water. When cold water is used it is generally put in at the checks through the injector pipe. When looking for defects, such as cracked plates, or corrosion, they will generally indicate themselves by allowing some water or steam to force its way out at the place where the defect exists. A defect in the fire-box will often show itself by a leak at the mud ring. When a fire-box plate is cracked it usually opens suddenly, so that the leak shows at once. If the tubes which are leaky are not stopped by caulking, the tube plate should be examined to see whether it is cracked.

Internal Corrosion. Internal corrosion, however, can only be discovered by an internal inspection of the boiler. To do this the dome governor must be taken off, and, after entering the boiler, every part should be examined carefully. In some cases the tubes must be taken out, so that every portion of the boiler can be reached. It is more essential to make an internal inspection when it is known that the water is of a corrosive character.

Broken Stay Bolts. While broken stay bolts may be indicated by the bulging of the plates or by sounding, the only way of examining them is by an internal inspection. To prevent scale and incrustation the best water that can be obtained should be used. Should, however, the water contain much solid matter, the boiler must be blown out and washed out often. If a hard scale is formed it is necessary to take out the tubes, the crown bearings, and clean them and the inside of the boiler thoroughly. The interior of the tubes should be cleaned out every time the engine is washed. This may be done by the use of a brush cleaner.

Cleaning Smoke-box. The smoke-box door should be opened occasionally to see whether the petticoat pipe, deflection plates, and wire netting are in good condition and properly secured. The smoke-box should be kept clear of ashes and cinders, and it should be securely fastened so as to be air tight. If the exhaust nozzles become obstructed by a collection of oil and dirt, they should be cleaned out, and the nozzles should be adjusted so that blast from the exhaust pipes is discharged in the center of the chimney.

Grate Bars. When examining the grate bars, it should be seen that they are not bent, burned out, or broken, in which case the imperfect bars should be replaced.

Throttle Valve. The throttle valve should be examined to see that it is steam tight. This can be learned by observing whether steam escapes from the exhaust pipe or cylinder cocks when the reverse lever is in full gear and the valve partly closed. If the throttle valve leaks, steam will accumulate in the cylinder and may be condensed, which may cause a serious accident. If the throttle valve leaks, it should be reground before making another run.

Safety Valve. When testing the boiler, particular attention should be paid to the safety valve to see that it blows off at the required pressure, and that the springs are in good condition. The steam gauge at the time of making the pressure test should be examined to see that it indicates the steam pressure correctly, and it should be compared with the test gauge, and any incorrectness should be adjusted.

Gauge Cocks and Water Glass. The gauge cocks and water glass should be tested to see that they indicate the proper water level, and the sediment and mud should be blown out before starting on a run. It is important to know whether the injectors are working satisfactorily, and if either of them is out of order a new one should be substituted in its place.

Piston Packing. Care should be taken to notice that the piston packing is not too loose and to find out if it works properly. This may be indicated while running by a peculiar sound which takes place between and after each discharge of steam. If the packing leaks, it may also be indicated by the escaping of steam from both the cylinder cocks just after the crank passes the dead point. This may also happen, however, if either or both of the main valves leak, but by careful observation the engineer can usually tell what and where the trouble is. It may also happen that the follower plate of the piston is bolted so hard against the piston head that it prevents the packing rings from moving. If the packing is too loose, it may be set out by means of nuts, in case a packing of that kind is used; if, however, a plain snap ring is used, it may have to be replaced. The packing should be examined to see that it is in good condition, and in the case of soft packing it may be made tight by simply screwing up the nuts on the gland. Should the rod be found to be cut or scratched, it should be reground before the engine is again run.

Cross-head Guides. The cross-head guides should be lined up, and the lubricators should be examined to see that they are giving the cross-head slides the proper amount of oil. Should any lost motion be discovered between the cross-head and the guides, it should be taken up by means of gibs or liners.

Crank Pin. The crank pin should be examined for cracks and flaws, and the brass bearings on the connecting rods and coupling rods should be adjusted to take up any wear that has taken place. When keying up the brasses care should be taken that they do not bind on the journals. It is always better to have some little play in the bearings than to have them too tight.

Valve Gear. The valve gear should be inspected to see that it is obtaining its proper lubrication, and the eccentrics and eccentric straps should be examined to see that they are properly keyed and that the strap is sliding properly on the eccentric.

Should the engine have given any notification of going lame before it has been run in to be inspected, it may probably have been due to the fact that the eccentrics are either too long or too short. If this is the case, they should be examined to find out whether the cut-off is taking place at the same points of the stroke on each side of the engine.

Wheels. All the wheels of the engine and tender should be carefully examined to see that they are sound. The condition of the wheels will affect the clear sound which comes from striking them with a hammer. If they are sound they will give out a peculiar clear ring, whereas if they are fractured the sound will be quite dull. The wheels should also be personally inspected for cracks, as sometimes a crack in a certain portion of the wheels will not affect the clear sound which comes from the hammer blow.

Should the engine have had any lost motion in it, it will have been indicated by a pound or thump. A loose piston rod in a cross-head or piston may cause a pound, or if the piston strikes a cylinder head it may cause a thump. There may also be some lost motion in the connecting rod bearing; just where, however, the lost motion may occur, can best be told by the engineer, who should stand at the side of the connecting rods and driving wheels and have his fireman open the throttle valve, so as to move the engine slowly.

Injector. Should the injector be found to work improperly, it may be due to an air leak in the suction pipe, a leak in the steam valve, or to a leak in the boiler check valve. In some cases, the boiler check valves may stick fast, so that they should be also examined.

Oil Cups. All of the oil cups should be cleaned, spindles adjusted, and the oil holes freed from dirt or gum. The oil cups should be screwed tight in the oil holes. It may be desirable, occasionally, to lift the engine and tender from the tracks and lubricate the bearing plates with tallow. This will cause them to more easily adjust themselves to the curves of the tracks.

Brakes. The brakes on the engine and tender should be examined to see that they are in good working order, that the bolts, nuts, and keys are all secure; the levers, rods, and chains properly connected and the shoes properly fastened and not too much worn.

Water Tank. The water tank should be examined occasionally to see whether it is clean, and also to see that there is no obstruction over the strainers on the water supply pipe.

Sand Box. The sand box should also be filled before starting on a run. The bell-rope or bell-ringer should be tested and the headlight should be examined to see that it is either properly trimmed or that the gas or electricity is in good working condition.

Starting an Engine. After the engine has been thoroughly inspected and the fire started and the engine ready to go, the engine should be started by opening the throttle slowly with the reverse lever in full gear. If the driving wheels are apt to slide and the train cannot be started otherwise, the rails must be sanded by opening the valves in the sand box. Having the train in motion and the engine gaining in speed, the reverse lever should be thrown back nearer the center of the quadrant or sector so as to cut off the steam. The throttle should be wide open and the speed regulated entirely by the reverse lever, unless the speed becomes excessive with an open throttle, in which case, of course, it becomes necessary to partly close the throttle.

Boiler Feeding. The feeding of the boiler should, if possible, be continuous, and the quantity of water pumped into it should be adjusted to the amount of work which the engine is doing. The water should be maintained at a medium level to prevent overheating of the crown plates, or to prevent priming or foaming. If the water is too low it may injure the crown sheet, and if it is too high it may carry water over into the engine cylinder. Should the engine show any indications of priming, the cylinder cock should be opened at once, otherwise the cylinders, cylinder heads, or pistons, may be broken. The throttle valve should be partly closed so as to be able to tell where the proper water level is in the boiler. If there is too much water in the boiler the feed may be shut off and the engine run slowly until the proper level is again obtained. Should the boiler be foaming, due to some impurity in the feed-water, it may be best to open the surface cock in the back end of the fire box, as foaming or priming may often be caused by oil or other floating impurities. The use of the surface blow-off cock will often remedy the trouble.

Precautions when Running. Of course, it is the duty of the engineer and fireman to carefully watch all the signals along the road according to the directions given them. When rounding a curve the speed of the train should be slowed down in proportion to the sharpness of the curve. On approaching an ascending grade the fireman should see that the fire is in good condition, and as much coal should be put on it as can be burned to advantage. The boiler should also be as full of water as safety will permit, and this water should all be ready for steaming when the grade is reached. In running up steep grades, allowance should be made for the effect of the inclination on the track to the water level in the boiler.

Stopping an Engine. When the engine is being stopped the steam should be shut off at a distance from the stop which will vary according to the nature of the grade and track, so that the engine can be gotten down to moderate speed before the stop is made. When steam has been shut off the reverse lever should be thrown into full gear, because in that position there is less compression of steam in the cylinders, and therefore not so much liability of raising the valve from its seat. When the end of the run is reached the fire should be so managed that there will be as little as possible remaining in the fire-box.

Inspection at the Round House. After the arrival of the engine at the round house it should be run over a pit, which is usually provided for the purpose, and the fire should be raked out of the fire-box by dropping the drop door, if there is one to the grate, or by turning the grate bars edgewise and allowing the fire to fall into the ash pan. After all the fire is withdrawn, the dampers and furnace doors should be closed so as not to allow the cooling of the fire box and tubes too rapidly. If the boiler requires blowing out, the blow-out cocks should be opened, and after all the water has escaped the engine should be left to stand until it has cooled off. If there are any indications of a large amount of mud or sediment in the boiler, the manholes at the bottom of the fire-box and the cover of the mud drum should be taken off and as much of the mud removed as can be scraped out A hose pipe attached to a force pump should then be inserted through these openings and a strong stream of water forced into the boiler. If the boiler is hot this should be done with hot water, but if the boiler has cooled off, it may be done with cold water.

Should there be any damage to a grate bar, it must be replaced with a new one. As soon as the engine is run into the engine house the cylinder cock should be opened and left open while it is standing still, so that any condensed water may escape. All grease and oil on the engine should be wiped off, and each part should be examined to see that it is in good condition.

Laying up the Engine. If the engine is to be laid up in cold weather, no water must be left in the tender, boiler, or in any of the pipes. Should this be impossible on account of having to start up the boiler in a short time, a light fire should be kept in the boiler, sufficient to make steam enough to warm the water in the tender. The water, however, should be emptied from the pumps, injectors, feed and supply pipes. This may be done by opening the pet cocks and closing the tender valves and uncoupling the hose, which will allow the water in the supply pipes to run out. After the engine has run a few revolutions, the pumps will be emptied. The pipes and the pumps can also be prevented from freezing by uncoupling the hose after the tender valves are closed and the pet cocks opened. Steam is then admitted into the supply pipes by the heater cocks, which forces part of the water, which is in the pumps, out of the pet cocks and warms the rest. It is better, however, if the engine is to be laid up for any considerable time, to always empty every part of any water which it may contain.

Points on Engine Running.

Duty of the Engineer. The duty of the engineer is to thoroughly inspect his engine for possible defects of machinery. He should know the condition of the fire-box, grate-bars, etc.; that gauge and water glass cocks are open and working freely, that the crown-sheet is covered with sufficient water to protect it from injury, and that the tender has been supplied with water. He should also know the condition of the engineer's brake valve and air pump, and take such other precautions as will prevent an engine failure.

Engine Tools. The engine should be provided with such tools as are found necessary in everyday work. This includes also tools with which to make repairs in case of accident. Rake, coal pick and shovel are classed as tools.

Engine Inspection. The engineer should satisfy himself by personal inspection that any repair work on valves, brasses, etc., has been properly done, that all movable parts have been returned to place and properly secured by bolts, set-screws or otherwise. The boiler should be examined to see that it is carrying the proper steam pressure by examining the safety valves and steam gauge, which should correspond with the prescribed pressure as established by the company.

Attention should be given to boiler attachments, such as gauge, cocks, water glasses, etc., and they should be inspected to see that they are open and working freely at all times.

Preparations for Starting. Before leaving the engine-house the cylinder-cocks should be open, so that any water or steam which is condensed in warming the cylinders can escape. The engineer should know that the tank is filled with water, the sand-box with sand, and that there is a proper supply of oil, waste, packing, tools and lamps on the engine. Before the engine is started from the engine-house the bell should be rung and time enough allowed for any workmen employed about the engine to get out of the way. While running from the engine-house to the train the engineer should observe very carefully the working of all the parts of his engine, and as far as possible see that they are in good working condition. If the engine is without steam or air-brake, the fireman should operate the hand-brake on the tender when it is needed. Before starting, the engineer should see that the engine and tender are securely coupled together, that the frictional parts are properly lubricated, that the fire is in good condition, and that the requisite quantity of steam has been generated. If the steam is too low, the blower should be started, which stimulates the fire. The air-brakes should also be tested.

Starting the Engine. After the signal to start is given by the conductor, the engineer places the reverse lever so that the valve will work either in full gear or very near it. The throttle should then be opened slowly, so as to start the train gradually. If the train is a very heavy one, it is best to back the engine so as to take up the slack of the train, which pushes the cars together, so that there will be no space between them, and compresses the car draw-springs. When the cars stand in this way, those at the front end of the train are started one after another, which makes the start easier than it would be if it were necessary to start them all at once. If the throttle is opened too rapidly, the driving-wheels are apt to slip, but with a heavy train, even with the greatest care, this is liable to occur. If the train cannot be started otherwise, the rails must be sanded by opening the valves in the sand-box. As little sand should be used as possible, because the resistance of cars running on sanded rails is somewhat greater than on clean rails, and thus the train is more difficult to draw after it reaches the rails to which sand has been applied.

Attaining the Proper Speed. After the train has been slowly set in motion, the engineer should ascertain by watching whether the whole train moves together, and that none of the couplings are broken in starting, and also whether any signal is given to stop, as is sometimes necessary after the train has started. On leaving the station, he should observe whether all the signals indicate that the track is clear, and that the switches are set right, and also look out for obstructions on the track. The train should always be run slowly and cautiously until it has passed all the frogs, switches, and crossings of the station yard, and not until the engineer has seen that everything is in order, should he run at full speed. As

the engine gains in speed the reverse lever should be thrown back near the center of the quandrant so as to attain shorter cut-off.

Economical Use of Steam. After the engine is started it is more economical to use steam at a high pressure, which is done by keeping the throttle-valve wide open, and then regulating the speed by cutting off shorter, than it is to throttle the steam. If the speed is reduced by partly closing the throttle-valve, the steam is wire-drawn, and it then produces less useful effect than it would if it was admitted into the cylinder at full pressure. There is also another practical difficulty in using steam of a high pressure and running with the trottle wide open and regulating the speed with the reverse lever alone. The link-motion, as has already been explained, will not be effective in cutting off at a point below about one-quarter of the stroke. Now it often happens, even when cutting off at that short point, with light trains on a level or slightly descending grade, that the speed will be too great if the throttle is wide open and with full steam pressure in the boiler. When this is the case, it is absolutely necessary to reduce the speed by partly closing the throttle.

Uniform speed should be maintained if possible, and in order to do so the distance between stopping points should be divided, and the time given for running it into as small divisions as convenient, so as to be able to tell as often as possible whether the run is being made too fast or too slow.

Feeding the Boiler. The feeding of the boiler should, if possible, be continuous, and the quantity of water pumped into it should be adjusted to the amount of work which the engine is doing. Ordinarily one injector is more than sufficient for feeding the boiler, so that usually only the one on the right side of the engine, where the engineer stands, is used. In feeding the boiler it must be seen that the water is neither too high nor too low. If it is too low there will be danger of overheating the crown-plates, or even of an explosion; if it is too high, the steam space in the boiler is diminished unnecessarily, and will cause the water to rise in the form of a spray, and thus be carried into the cylinders with the steam, or the boiler will prime or foam, as it is called. This water, if it collects in the cylinder, as already explained, may by the concussion produced by the motion of the piston break the cylinder.

Priming of Boilers. Impure water, grease, oil, or soap are the chief causes of priming. Mud, or other dirt, is also liable to cause it.

As steam is usually drawn from the top of the dome to which the safety-valves are attached, the tendency to prime is very much increased when they are blowing off, so that some engines have two domes, from both of which the supply of steam is sometimes drawn. It is generally advisable, when the safety-valves begin blowing off steam, to reduce the pressure in the boiler as soon as possible, not only because when they are blowing off it tends to produce priming, but because the steam which escapes from them is wasted. The pressure can be most economically reduced either by increasing the amount of water which is fed into the boiler, or by opening the heater-cocks and allowing the steam to escape into the tank, and thus warming the water in the tank. If the boiler is too full, the former method cannot be employed, and in heating the water in the tank the engineer must be careful not to get it too hot, because in that case neither the pumps nor the injectors will work satisfactorily. If the steam pressure cannot be reduced in any other way, the furnace door must be partly opened.

Priming may be sometimes due to the formation of foam on the surface of the water, for which reason priming is often called foaming.

Causes and Remedy of Priming. The principal causes of priming in ordinary practice are due to defective circulation, too little steam room, impure water, or too much water in the boiler. The priming of a boiler can generally be discovered by the white appearance of the steam which escapes from the chimney and the cylinder cocks. Dry steam always has a bluish color. When an engine primes or works water into the cylinders, it is usually indicated by a peculiar muffled or dead sound of the exhaust, which from this cause loses its distinctly defined and sharp sound. This can be observed best when the furnace door is opened. It is also indicated by the discharge from the gauge-cocks as the steam from the upper cocks is not clear, but is mixed with water. The water will also rise in the glass water-gauge, and it will not indicate correctly the quantity of water in the boiler.

As soon as there are any indications of priming, foaming, or that the water is working into the cylinders, the cylinder cocks should be opened at once, otherwise the cylinders, cylinder-heads, or pistons may be broken. The throttle-valve should be either partly or entirely closed. When this is done the foaming will in most cases cease for the time, so that the engineer can tell the true water level in the boiler. When the flow of steam from the boiler is stopped the priming usually stops, and the true level of the water will be shown by the gauge-cocks and glass water-gauge.

If it is found that there is too much water in the boiler, it is best to shut off the feed, and in some cases the blow-off cock should be opened. The latter is, however, attended with some danger, because if any obstruction should get into the blow-off cock, or it should stick fast, so that it cannot be closed, all the water would escape from the boiler, and with a heavy fire in the fire-box there would be great danger of overheating, and thus injuring the boiler or of "burning" it, as it is ordinarily termed. In that event it will be imperative to put out the fire at once. Another method of affording relief, if a boiler foams, is to place what is called a surface-cock in the back end of the fire-box, about half-way between the upper and lower gauge-cocks. With such a cock, the water can be blown off from the surface instead of from the bottom.

As foaming or priming is often caused by oil or other floating impurities on the surface, they can be blown out of the boiler by means of the surface blow-off. A perforated pipe which extends for some distance along the surface of the water inside the boiler is sometimes attached to the surface-cock, so that the water which is blown off will be drawn from a number of points along the surface. If it is essential to keep the train in motion when the boiler foams, it is a good plan to place the reverse lever in full gear and open the throttle valve very little, so as to diminish and equalize the flow of steam into the cylinders.

If the steam is rising rapidly when foaming begins, it will be well to cool the boiler off by opening the furnace door part way. This means of relief should, however, be used as little as possible, because there is always danger of causing the tubes or other parts of the boiler to leak, by either heating or cooling suddenly or rapidly. If the engine primes when there is but little water in the boiler, and at a time when the steam is rising rapidly, it may sometimes be remedied by increasing the amount of feed-water, and thus partly cooling the water inside. The use of pure water, careful firing so as to keep the steam pressure regular, feeding the boiler so that the level of the water will be nearly uniform, and then starting the engine carefully by opening the throttle-valve gradually, are the most effective means in practice of preventing a locomotive boiler from priming.

Priming is very uneconomical because it causes a great waste by the escape of heat contained in the hot water which passes through the cylinders and which does no work. When steam is mixed with a great deal of water, the initial pressure on the piston, if the engine is cutting off short, will not be so great as it would be if dry steam was used. Wet steam is also more difficult to exhaust from the cylinders than that which is dry, and therefore the back pressure on the piston is greater when the boiler primes than when dry steam alone is used.

Precautions When Running.—When running on the open road the track in front of the locomotive should be constantly watched, and from time to time the train of cars, especially if it is a long one, should be observed to see that it is in good condition. Every signal should be observed and their instructions strictly adhered to. In running through a curve, the speed of the train should always be moderated in proportion to the sharpness of the curve, and before reaching it, as the train has a tendency to continue in a straight line, and there is thus danger of running off the track. The higher the speed, of course, the greater is the resistance which is required to prevent the train from running in a straight line, and consequently the greater is the strain which is thrown on the flanges of the wheels and on the rails and axles. On a curve it is also impossible, usually, to see further than a short distance ahead, and therefore, if the train is running very fast, it cannot be stopped in time, should there be any obstruction or danger on the track. On approaching an ascending grade the fireman should see that the fire is in good condition, and as much coal should be put on it as can be burned to advantage. The boiler should be filled as full of water as it safely can, without danger of priming, and this water should be heated as hot as possible without blowing off steam at the safety-valves. The object of this is to have a supply of water already heated before reaching the grade.

If, as often happens with a heavy train, the boiler will not

make as much steam as the engine consumes, and there is a large supply of hot water in the boiler, it can be used as a reserve, should it be necessary to do so, without danger of injury to the boiler. If there is so little water in the boiler that it would be dangerous to allow it to get lower, then it becomes necessary to feed cold water as rapidly as the hot water escapes in the form of steam. When the engine is working hard, it is often impossible to heat all this cold water as fast as it is pumped into the boiler without reducing the steam pressure until there is not sufficient power to boiler, at the critical point on the grade, where the engine is most pull the train. If, however, there is a supply of hot water in the liable to fail, the pump or injector can be partly shut off, and thus less water will be fed into the boiler, and the steam pressure will be maintained without danger. Undoubtedly it is better to feed locomotive boilers uniformly, if that is possible, but it often happens that a reserve supply of hot water in the boiler enables an engine to pull a train up the most difficult place, whereas, without such a supply, the locomotive would stick fast. This fact gives engines with large boilers much advantage over those with small ones.

In running up steep grades, allowance should always be made for the effect of the inclination of the track upon the position of the water surface in the boiler, and also for the fact that as soon as the throttle valve is closed, and steam shut off, the surface of the water will be considerably lower than when the engine was working hard.

If the engine is not equipped with an automatic cylinder oiler, as soon as the top of the grade is reached the fireman should oil the main valves, because it can only be done when steam is shut off, as the oil will not run into the steam-chest when there is a pressure of steam in it; and as the valves are always subjected to the severest wear while pulling up a steep grade, the valves and valve-faces are apt to become dry. As saturated steam, to some extent, prevents valves from cutting, it is not so important that they be lubricated while the engine is working with steam; but as soon as steam is shut off they should be oiled, otherwise there is danger of their being injured by their friction on the valve-seats.

In running down grades, the engineer has the greatest possible cause for using every precaution, because not only is the train much more difficult to control, but usually frequent sharp curves prevent a view of the track for any considerable distance ahead. He should, therefore, watch the track in front of him with the greatest vigilance, so as to be ready to give the requisite signals to the brakemen to apply the brakes, or if the engine and train are provided with continuous brakes, to apply the latter, or even reverse his engine, in case of danger.

Preparing for a Stop. When running into a station, the speed should be checked so that the train will not enter with very great momentum. Therefore, at a distance varying according to the nature of the grades and track, the steam should be shut off, so that the speed will be reduced so much that the train under any circumstances will be under full control. It is always better to enter a station at too low speed than to run in too fast, because, if it is necessary, more steam can always be admitted to the cylinders to increase the speed before coming to a stop; whereas it is not so easy to stop the train if it is running too fast, and it becomes necessary to check it before entering the station. When steam is shut off the reverse lever should be thrown into full gear, because in that position there is less compression of steam in the cylinders, and therefore not so much liability of raising the valve from its seat.

Running at Night. Before it begins to grow dark, the headlight must be lighted and promptly trimmed, and the proper lamp signals placed in front of the engine. A lamp should always be placed in the cab, so as to throw its light on the steam-gauge, but not into the engineer's face, because he is unable to see distant signals so well if his eyes are exposed to the glare of a light near him. As objects which are passed cannot be seen distinctly, it is more difficult to tell the speed at which an engine is running than it is in the daytime, so that the time must be consulted frequently.

Running in Cold Weather. When running in cold weather, great care must be exercised to prevent the water in the pipes, and in the tender, from freezing. If it does, it will be almost certain to burst the pipes. To avoid this the heater-cocks must be opened, so as to keep the water in the tender warm. In excessively cold weather the engine should be run with greater caution than at other times, and everything should be more carefully inspected, as accidents are more likely to happen, owing to the frozen condition and consequent solidity of the track.

Running with Two Engines. When a train is run with two engines, both in front of it, the forward engineer always takes the management of the train. The engineer of the second engine must be guided by the signals of the one on the forward engine. In starting, the forward engine must be set in motion first, and then the one behind it. In stopping, the steam must be shut off first in the second engine. Likewise in decreasing the speed during the trip, the second engine must first regulate the flow of steam. If these precautions are not observed, the forward engine may easily be thrown from the track by the faster motion of the second one. When there are two engines the air-brakes should always be operated from the front engine, but the air-pump on the rear one should be kept running to assist in charging the brake reservoirs with compressed air. When a train is assisted by a "helper," placed behind the train, and therefore pushing it, the forward engine must likewise be set in motion first, and steam should be turned on in the rear engine only after a signal has been given by the engineer of the head engine.

Running Switching Engines. Switching engines should be moved carefully and severe shocks must be avoided, as the cars, the goods with which they are loaded, and the persons employed about them may be injured. In switching service it is of special importance that the engineer give a distinct signal with the whistle or bell before every movement of the engine, in order to warn in time those who at such times often stand on the track in the way of the engine or cars, or the persons engaged in loading, cleaning or repairing the cars, and thus give them time to get out of the way.

Making Long Stops. When a train stops for any length of time, the engineer should examine thoroughly all the parts of the engine. All the journals and wearing surfaces should be examined to see whether they are hot, which may be done by feeling them. If any of them have become very much heated, they must be cooled by throwing cold water on them, and then thoroughly oiled. The working parts should be thoroughly lubricated, as already explained.

Blowing Out Boilers. In order to keep the boiler clean—that is, as free as possible from sand, sediment or incrustation—

it is necessary to blow it out frequently, if the water which is used contains much solid or incrustating matter. With "bad water" the boiler should be blown out as often as possible. On some roads this is done after each trip. In blowing a boiler out, the blow-off cocks must be left open, and after all the water has escaped the engine should be left to stand until it is cooled off. If there is any considerable accumulation of mud or sediment, the hand-holes at the bottom of the fire-box and the cover to the mud-drum should be taken off, and as much of the mud removed as can be scraped out through those apertures. A hose-pipe attached to the hose of a force pump should then be inserted through these same openings, and a strong stream of water forced into the boiler. By this means much of the loose mud and scale will be washed out. The oftener this is repeated, of course, the cleaner can a boiler be kept. If a large amount of incrustation or mud has accumulated about the tubes, some or all of them must be taken out, so as to be able to remove the dirt.

After an engine is blown out, under no circumstances, excepting absolute necessity, should it be filled with cold water until it is cooled off. It should be remembered that any sudden change of temperature in a boiler subjects it to very great strains, and incurs the danger of cracking the fire-box plates, or causing the tubes to leak.

The tender should also be cleaned of the mud which settles in it from time to time; but it is not necessary to do this as often as it is to clean the boiler. The strainers in the tank over the water-supply pipes should be examined and cleaned frequently. All the plates and flues should have the soot which sticks to them thoroughly cleaned off.

Although the cleaning of the boiler and the grates is usually committed to a special set of men, yet the locomotive engineer should examine them personally to see that it is properly done. He should pay attention to the condition of the grate, and see whether it is level and smooth. As soon as one or more of the bars are bent crooked, they usually burn out. If one of the bars is burned out, the fire falls through the hole that it leaves into the ash-pan, and then the fire under the grate will heat it red hot, and finally may melt or "burn" every bar. Every grate-bar which is only a little damaged or bent must, therefore, be removed as

quickly as possible and replaced with a new one. An opening in the grate larger than the spaces between the bars allows a superfluous amount of cold air to enter the fire-box, and diminishes the steam-generating capacity of the boiler.

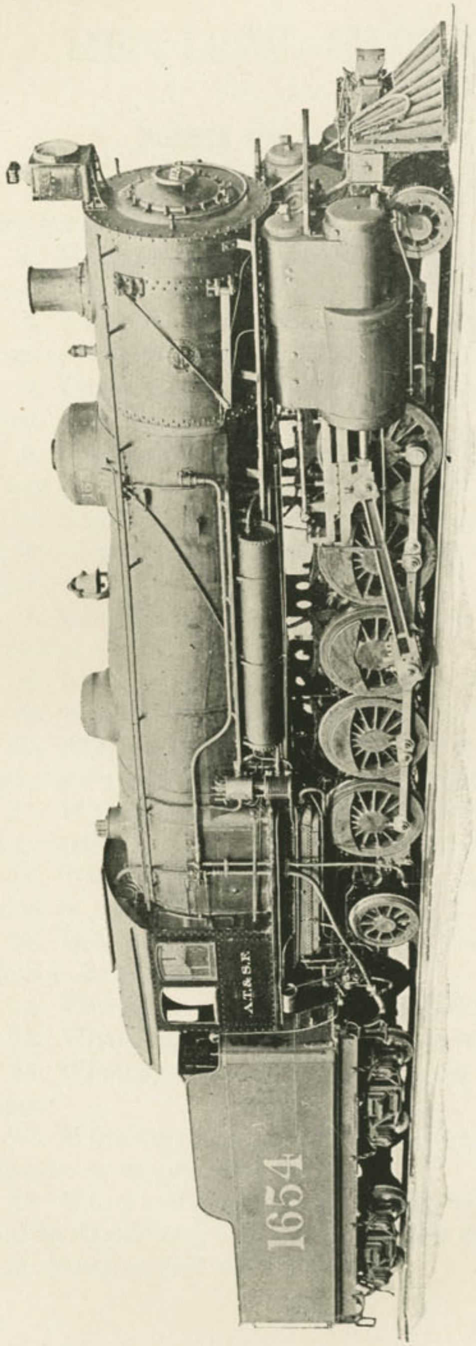
Care of Engine in the Engine House. As soon as the engine is run into the engine house, the cylinder-cocks should be opened and left open while it is standing still, so that the condensed water can escape. All grease which has escaped from the wearing surfaces and the dust or mud which adheres to the engine should be wiped off with cotton waste or rags. While this is being done every part should be thoroughly examined. If any defects are found, they should be reported to the proper person, whose business it is to have them repaired.

Laying Up the Engine. If engines are laid up in cold weather for any considerable time, no water must be left in the tender, boiler or any of the pipes. If, however, the engine must be soon used, and it is impracticable to let the water out of the boiler and tender, then, if exposed to the cold, a light fire must be kept in the boiler sufficient to make steam enough to warm the water in the tender. The water should, however, be drawn out of the pumps, injectors and the feed and supply pipes. This can be done by opening the pet-cocks and closing the tender-valves and uncoupling the hose, which will allow the water in the supply pipes to run out. By running the engine a few revolutions the pumps will then be emptied. The pipes and the pumps can also be prevented from freezing without uncoupling the hose if the tender-valves are closed and the pet-cock opened, and steam is then admitted into the supply pipes by the heater-cocks. This forces part of the water which is in the pumps out of the pet-cocks and warms the rest.

REVIEW QUESTIONS

POINTS ON ENGINE RUNNING.

1. What are the duties of an engineer in regard to inspecting his locomotive?
2. What precautions should an engineer take to see that his locomotive is in proper condition before starting?
3. Name the different parts of a locomotive which should be inspected by the engineer before starting.
4. Describe how you would start a train if the signal to start is given.
5. How should the valves and reverse levers be adjusted as the train attains its proper speed?
6. Suppose with a short cut-off the engine is running too fast, what would you do to slow down the train without putting on the brakes?
7. Explain how the boiler should be fed so as to get the best results.
8. Name several causes for priming in a boiler.
9. When priming is first discovered, what should be done?
10. Suppose priming is caused by too much water in the boiler, what would you do to decrease the priming?
11. If the foaming or priming is caused by oil or other flowing impurities, how can they be removed?
12. When running at a high speed, what precaution should be taken in going around curves?
13. How much water should be in the boiler before a large grade is to be ascended?
14. How do you prepare your engine for a stop?
15. What precaution should be taken when running at night?
16. What precaution should be taken when running in cold weather?
17. When two engines are coupled to the same train, describe the proper management of them.
18. When starting a train having two engines, which one should be started and which one should be stopped first, and which engine should control the air brakes?



SANTA FE, OR 2-10-2, TYPE OF LOCOMOTIVE FOR HEAVY FREIGHT SERVICE—ATCHISON, TOPEKA AND SANTA FE RAILROAD
(Baldwin Locomotive Works)

Railway Motor Cars.

The self-contained motor car for railway use has had a considerable growth in this country, as it possesses many desirable features of operation, especially on suburban and branch lines, which have made it attractive to railway engineers.

Types of Motor Cars. In general, motor cars may be divided into three types, each of which has its inherent advantages and disadvantages. These are the gasoline type, the gas-electric type, and the steam type.

Taking the class of motor cars as a whole, they seem to give good service mechanically, but the principal disadvantage is that the motor power and car are inseparable, and it is necessary to put the whole car out of commission when the mechanical portion needs attention. Another objection to their use on standard railroads seems to be that they cannot be handled in the same place and manner as the other motor power of the road.

They are particularly adapted to light passenger service, and have been used for this purpose both in this country and in Europe for some years.

Gasoline Type. In this type are included the gasoline motor cars, which have a direct mechanical drive from the gasoline engine. The most extensive development work in this country has been done by the Union Pacific Railway on this type.

The latest type of gasoline car used by the Union Pacific Railway is equipped with a 200 horse power motor, especially built for the rough service incident to suburban lines. The motor consists of six cylinders, ten inches in diameter by twelve inches stroke. The total weight of the car is 61,300 pounds, equivalent practically to 300 pounds per horse power. This car has been running regularly between Beatrice and Lincoln, Nebraska, and a number of other branch lines are being served with this type of car, which has shown remarkable regularity in service, and in some instances has proved superior to steam train service.

The average cost of fuel a year around, using 72 degree gasoline, amounts to 3½ cents per car mile. As a substitute for gasoline, California distillate has been used in regular service with good results. The distillate, being much cheaper than gasoline, reduces the cost per car mile, and it is expected that when denatured alcohol becomes low enough in price, this kind of fuel will come into use on these engines.

Another type of car which uses the gasoline motor with mechanical transmission is used for service in Yellowstone Park. This car has a four-cylinder gasoline motor, cylinder 6 x 6 inches, and develops 50 horse power at 700 revolutions per minute, the maximum speed of the car being about 35 miles per hour. The transmission is of the mechanical type, with three speeds forward and three reverse, with a chain drive of the Renold silent chain type.

Gasoline-Electric Type. A number of other railroads have been using gasoline motors with electrical transmission. Several of these types have been used in regular operation between Kansas City and Olathe, and are known as the Strang car. The transmission used in the Strang system is of the electrical type, the generator being direct connected to the motor, forming a self-containing generating unit. Directly from the brushes of the generator, main wires lead to a controller of the series parallel type; from this controller wires lead to an electric motor, hung on the axles of the front truck, according to Standard Electric Railway practice. A small storage battery is connected in multiple with the wires, between the generator and controller, and in one of the main wires, between the battery and the generator, is placed a rheostat, which is used for the purpose of temporarily converting the generator into a motor when starting the engine. With this type of car, it is claimed that the gasoline consumption has averaged about one-half of a gallon of gasoline per motor car mileage of sixty thousand miles. The equipment of the Strang car consists of a 100 horse power gasoline engine and 50 kilowatt generator, two 65 horse power motors, and a storage battery of 112 cells with 250 ampere hour capacity.

Another type of gasoline motor car with electric transmission is used on the St. Joseph Traction Co. lines. The service of this car consists in hauling from one to three trailers, three round trips per day, over a road 11½ miles in length, making the above trip in 35 minutes, with four stops, the heaviest grade being 1½ per cent. It is claimed that with one trailer, the gasoline consumption is ¾ of a gallon per mile. The motor of this car consists of a four-cylinder 70 horse power gas engine, direct connected to a 50 kilowatt 250 volt generator in parallel, with which is connected a battery. Four 50 horse power motors are used on the trucks.

Another type of gasoline electric car is built by the General Electric Co. The equipment of this car consists of an eight-cylinder gasoline motor of about 150 horse power, which is direct connected to an eight pole 90 kilowatt generator of the commutating pole type. There is an exciter of 3½ kilowatt capacity, for the purpose of exciting the fields of the main generator and effecting the variable voltage control. From the generator, wires are led to two 65 horse power motors, situated one on each truck of the car. These motors are also connected in parallel, the required torque or speed being obtained by varying the field current of the generator through a separately constructed controller, which is suitably arranged to give out fifteen steps. The gasoline motor is of the four cycle type, equipped with two separate systems of ignition, one high tension system using an induction coil, connected to a four volt storage battery, the other being used to make a make-and-break system connected to a direct driven low tension magneto. The carburetor is of the single nozzle, long compensated type, gasoline being supplied to it by means of a diaphragm pump. Radiators for cooling the water are located on the roof of the car. The claimed speed of the motor is 550 revolutions per minute. The car is heated by passing as much of the exhaust gases through pipes as is required. These pipes are placed in approximately the same position as steam pipes in the Standard Railway coach.

Steam Motor Cars. In the steam motor car field, one of the most interesting cars is used on the Canadian Pacific Railway. One of these cars is in operation between Montreal and Vaudreuil, a distance of 24 miles, giving a service of three round trips per day on a regular schedule. The boiler is of the return tube marine type, carrying 180 pounds pressure, equipped with superheated coils and a Morrison furnace, brick-lined. Crude oil is used as fuel, with the burner of the Booth type. The cylinders are 11 inches in diameter by 15 inches stroke. The valves are of the piston type and are fitted with the Walschaert gear.

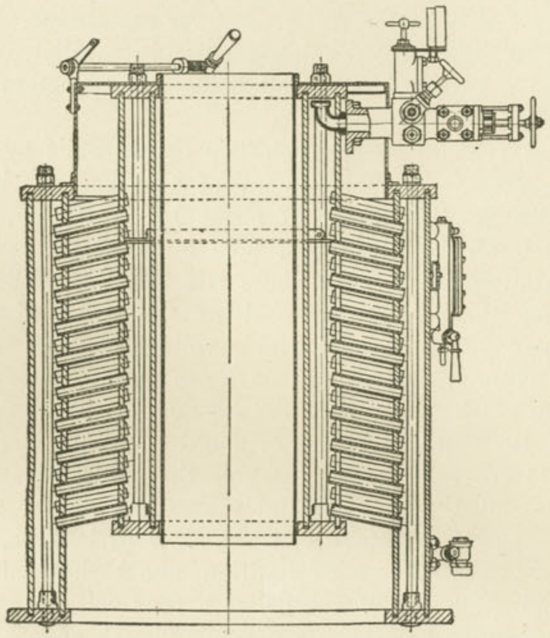


Fig. 1.

GANZ BOILER.

Ganz Car. Motor cars of this type are being used by four different roads. The boiler or steam generator, as shown in Fig. 1, is of special design, carrying a working pressure of 270 pounds, the steam being superheated. The boiler capacity is rated at 120 horse power. The steam motor is of the enclosed type with compound cylinders, all the moving parts running in oil. It is mounted on the forward truck and drives the rear axle through one set of gears. The cars are designed to maintain a speed of 35 miles per hour on a level track, and the

average fuel consumption is claimed to be from ten to twelve pounds of coal per mile.

Ganz Steam Motor Car Used on the Erie Railroad. The Erie Railroad is using on one of its suburban lines, near New York, a Ganz steam motor car, which consists of two compound enclosed steam motors of 60 horse power each, which are mounted on the forward truck and drive the axles through gearing. In the forward end of the car above the truck is a steam generator, which furnishes superheated steam at 270 lbs. pressure for the motors.

The car body is of wooden construction, and in exterior appearance is very similar to a composite passenger and baggage suburban car. It measures 58 feet over all and seats 50 passengers. The compartment at the forward end is 6 feet long, and contains the steam generator with its accompanying pumps, and also the control apparatus for the motors, engineer's brake valve, etc. The fuel, which is either anthracite coal or coke, is carried in a bunker in the forward end of the car, projecting out beyond the car and arranged to be filled from the outside. This bunker will hold enough coal for a continuous run of 50 miles. Just back of the generator room is a 6 foot compartment for baggage, behind which is a smoking compartment to seat 12 passengers. The remainder of the car is a general passenger compartment. This car weighs 45 tons in working order. The car which is used by the Chicago, Rock Island & Pacific Railway weighs but 26 tons, and is of approximately the same size. This difference in weight is due to the fact that the Rock Island car is of all steel construction, while the Erie car has a wooden body.

The steam motors have cylinders 4.7 and 6.7 x 5.5 in., and are arranged so that either can be operated independently, or both work together. The maximum tractive effort is 3,700 lbs. They are completely enclosed in dust proof cases, which are partially filled with oil, so that all moving parts receive continuous and thorough lubrication. The cylinders are steam jacketed, and the motors operate at a normal speed of 600 r. p. m., although they will run satisfactorily up to 900 r. p. m. A by-pass valve is provided for admitting high pressure steam to the low pressure cylinder to increase the tractive effort at starting, or when otherwise necessary. The motors are hung from the frame of the truck by spring suspension, the steam connections to the generator being flexible. Universal joints are fitted to all of the operating rods for controlling the motors. There is an intermediate shaft interposed between the crankshaft and the driving axle, which carries three gears, one being in permanent engagement with the gear wheel on the axle, and the other two being fitted with friction clutches. These are of different diameters, and can be thrown in, one at a time, one combination giving full gear and the other half gear speed.

The steam generator, Fig. 1, is 42 inches in diameter and 5 feet high. It is of the water tube non-explosive type, and consists essentially of four steel cylinders arranged concentrically. The spaces between the two outer cylinders and the two inner ones form the water legs of the boiler, and these two spaces are connected by a large number of small tubes, which constitute the bulk of the heating surface of the boiler. The water level is below the upper tubes, and hence these act as a superheater. The total amount of water in the boiler is comparatively small, and a continuous feed is provided from the pumps. This boiler has a heating surface of 212 square feet, and a grate area of 6 square feet. It is rated at 120 horse power, delivering the superheated steam at 279 lbs. pressure. It is claimed that steam at this pressure can be obtained in from 20 to 30 minutes from cold water, using either coke or anthracite coal.

Provision has been made for exposing the tubes for cleaning, and the feed pipe is arranged so that the feed water assists in cleaning out any mud that clings to the tubes. The water supply is carried in a tank of 600 gallons capacity, built in the underframe of the car.

Compound, Superheated Steam, Motor Car Used on the Chicago, Rock Island & Pacific Railroad. Steam motor cars are also used on the Chicago, Rock Island & Pacific Railroad. The motive power of these cars consists of a 250 horse power, two-cylinder compound steam engine, having cylinders $9\frac{1}{4}$ and $14\frac{1}{2}$-12 inches, operated by superheated steam of 250 lbs. pressure, generated in a horizontal return tubular boiler. The cylinders drive a pair of 38 inch wheels, forming the trailing wheels of the leading or motor truck. The car is of steel construction similar to Fig. 2, with interior finish of wood, is 55 feet 9 inches total

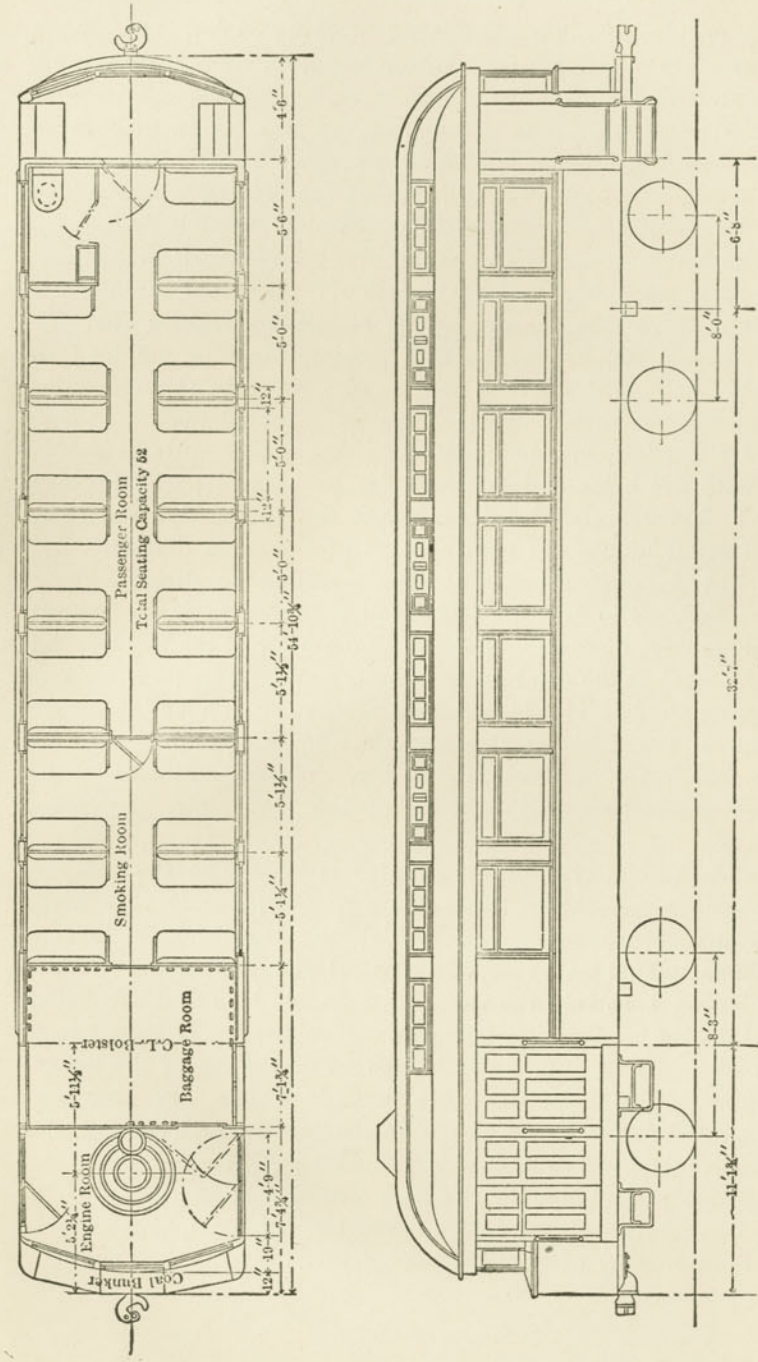


Fig. 2. Elevation and Plan of Steam Motor Car Used on the Chicago, Rock Island and Pacific Railroad.

length, weighs 100,000 pounds in working order, and has a capacity of 40 passengers, in addition to a good sized baggage compartment. Test runs have shown it to be capable of speeds of 60 miles per hour. The distribution of weights is such as to give 38,300 lbs. on the trailing truck, and 61,700 lbs. on the motor truck, of which 34,400 lbs. is on the driving wheels. The theoretical tractive effort, working compound, is 4,300 lbs.

The boiler is a very interesting design, being altogether different from anything that has previously been applied to a car of this type in this country. The conditions require that the largest amount of heating surface possible shall be obtained in the very small space allowed, and, since a fire tube type of boiler was desired, the return tubular type was decided upon. It consists of a fire box, 33⅛ inches long by 43¼ inches wide, which is fitted with fire brick and arranged for burning oil; 214 1¼ inch tubes, 3 feet 9 inches long, extend to the combustion chamber, and an equal number of return tubes of the same diameter and 3 feet 11½ inches long terminate in the smoke box directly above the fire box. The barrel of the boiler, which is in one sheet, 61¾ inches long, measures 49 inches in diameter at the fire box end and 44 inches at the combustion chamber end. The total amount of heating surface is 624.4 square feet, of which 527.8 square feet are in the tubes, 37.6 square feet in the fire box, and 59 square feet in the combustion chamber. The arrangement of the inclined smokestack and location of the dome, etc., is shown in Fig. 3.

A smoke box type of superheater is located in the combustion chamber, where the temperature of the gases is very high. This superheater consists of a header, divided transversely into two compartments by means of a vertical partition, and 16 superheated tubes, bent into the shape of a double loop and extending down into the combustion chamber. This header is bolted to a cast steel saddle casting, which is secured on the top of the boiler. The steam passes from the dome through a short dry pipe into the saturated steam compartment in the header, and through the superheater loops into the superheated compartment, and then through the steam pipe to the high pressure steam chest. The boiler is securely fastened to the motor truck frames, thus eliminating the necessity of flexible steam joints.

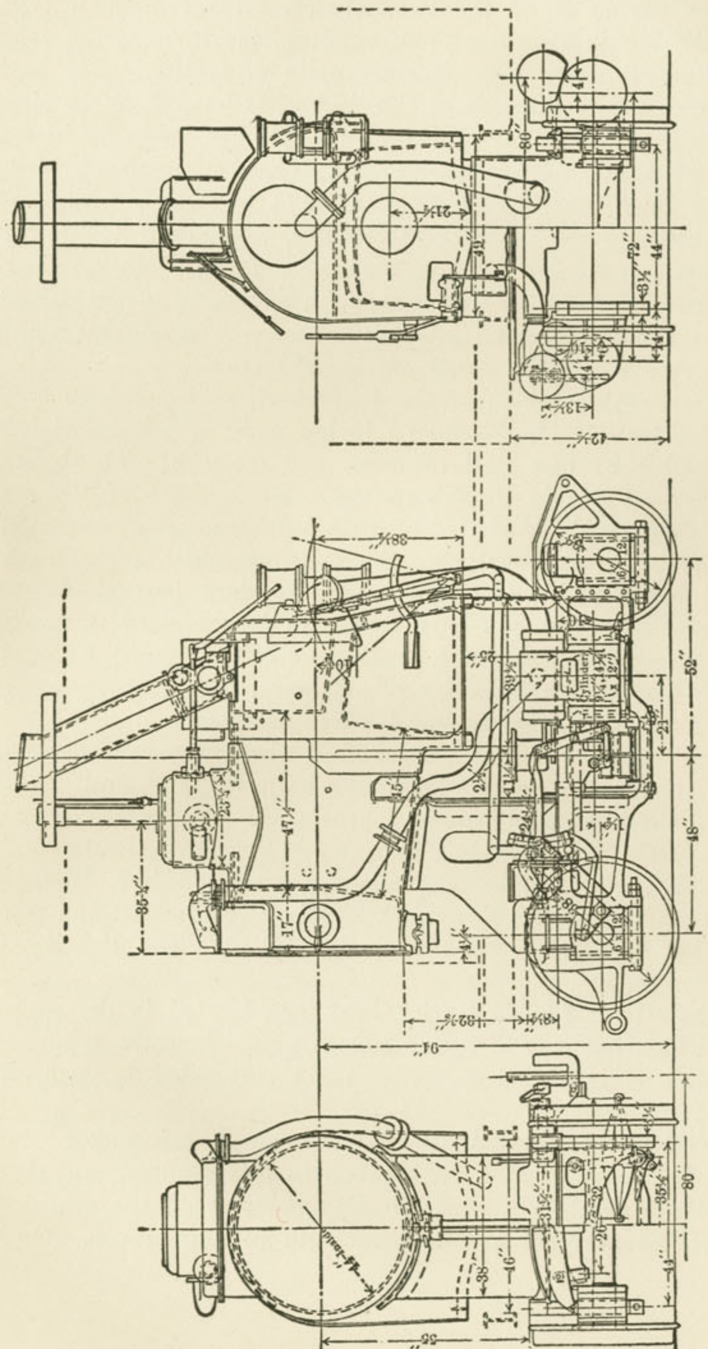


Fig. 3. Steam Motor Truck Used on the Chicago, Rock Island and Pacific Railroad.

The engine is of the two-cylinder, cross compound type, using the Mellin system of compounding, the intercepting valve being located in the high pressure cylinder casting. The high pressure cylinder, which is 9¼ x 12 inches, is located on the right side of the truck, and the low pressure cylinder, 14½ x 12 inches, on the left side. Both cylinders are equipped with piston valves, actuated by Walschaert valve gear. The cylinders, with their valve chamber, are in separate castings, and are bolted to the side frames of the motor truck, the centers being 69 inches ahead of the center of the driving wheels. Connection to the drivers is made through a small crosshead, having a single bar guide and short main rods located outside the frames.

The motor truck is of the four-wheel, spring bolster type, having cast steel side frames 3½ inches wide, which are rigidly tied together by cast steel transoms and crossties. The bolster is carried on double elliptic springs. The weight of the car, or driving journals, is carried by a semi-elliptic spring, suspended between two cross equalizers, the ends of which rest on the journal boxes, and the weight on the forward journals is carried by coil springs, one on top of each journal. In this manner a three-point suspension truck is obtained. The boiler is supported from the truck by plate braces, both transverse and longitudinal, which are stiffened where necessary.

The trailer truck is of the four-wheel, two-bar equalizer type, having swinging bolsters of the built up type, and has 34 inch wheels and 4¼ x 8 inch journals. Both the motor and trailer trucks are equipped with New York Air Brake Co.'s brakes, air, however, being obtained from an 8 inch Westinghouse air pump. The New York air signal equipment and Gold steam heating equipment have been applied. The iighting is by oil lamps.

The oil for fuel is carried in a tank located in the engine room, which has a capacity of 100 gallons. A water supply of 1000 gallons is caried in three tanks suspended beneath the floor of the car.

Development Abroad. The development of motor cars abroad has made greater strides than in this country, and there are a large number of roads in England and on the continent where different types of motor cars are in regular use. On a

number of German railroads the Daimler gasoline car, with a mechanical transmission, is used. It is equipped with a 30 horse power engine, having four cylinders, 5¼ inches diameter by 6¾ inches stroke. It is located in the middle of the car, and power is transmitted from the motor through a leather-faced cone friction clutch and through a sliding coil transmission to one of the axles. There are four forward speeds and one reverse.

In England a number of gasoline cars with electric transmission are used. The power plant consists of a four-cylinder horizontal gasoline engine, direct connected to a compound wound separately exciting generator of 55 kilowatt capacity, which furnishes current to two 50 horse power electric motors.

In Hungary a number of gasoline electric cars are also used. These have 70 horse power gasoline motors, direct connected to a 45 kilowatt generator, which supplies current to the ordinary railway type motor attached to the two axles. The usual series parallel controller is provided for starting, and after the car is once started the speed is almost entirely controlled by the throttle of the gas engine. Very satisfactory results are said to be obtained from these cars. The cars are equipped with air and hand brakes, air being supplied by a small compressor, driven from the outer end of the armature shaft. Jacket water from the motor is passed through the coils inside of the car for heating during the cold weather, and when no heat is required the water is passed through a coil of tubes on the roof.

Of the foreign steam cars in use, a large number are used on the Great Western Railway of England. The boiler, as shown in Fig. 4, is of the vertical fire tube type, with no superheater. The motor consists of two single expansion cylinders, 12 x 16 inches, coupled direct to the rear driving wheels, which in turn are coupled to the front drivers. Walschaert valve gear is used. The water supplied is carried in tanks hung underneath the car body midway between the trucks. A mechanical speed of 55 miles per hour has been obtained, although the average running speed is about 35 miles per hour.

Another type of steam motor car used in England differs chiefly from the ones used on the Great Western Railway in that the boiler is of the fire tube type and consists practically of two horizontal barrels, placed on either side of the central furnace. The boiler is placed transversely with reference to the car body, and rises directly upon the truck frame back of the forward axle. The cylinders are placed outside of the car, and the valves are operated by an ordinary link motion with a rocking shaft. The Lancashire and Yorkshire Railway has cars of a similar type, except that the boiler is of the usual locomotive type with horizontal fire tubes. The engine is built practically on the small locomotive design with the drivers coupled.

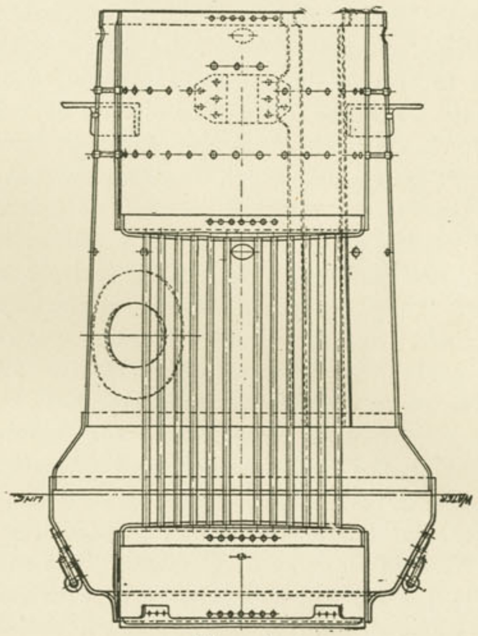


Fig. 4.

VERTICAL TYPE MOTOR CAR BOILER, USED ON THE GREAT WESTERN RAILWAY OF ENGLAND.

The Ganz motor cars are also used extensively in Central Europe, the boilers being placed at the forward end of the car together with the fuel bunker, feed-pumps and controlling apparatus. The motor is placed horizontal on the leading truck, and drives the rear axle through spur gears. The boiler consists of four concentric cylinders with headers, forming two

angular water spaces, joined together by means of slightly inclined steel water tubes. Within the inner cylinder is another cylinder of slightly smaller diameter, through which the fuel is fed to the grate below the flame, and hot gases pass around the water tubes to the stack. The motors are two cylinder cross compound. The largest of these cars in used is 80 horse power.

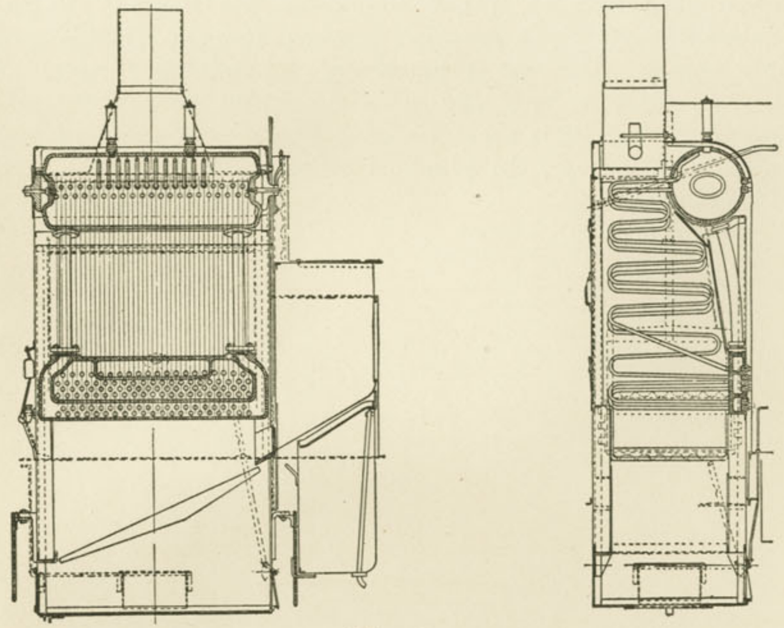


Fig. 5.

PURREY BOILER, USED ON FRENCH RAILWAY MOTOR CARS.

In France steam motor cars equipped with the Purrey system are used. The boiler shown in Fig. 5 is tubular, consisting of two drums, the lower one of rectangular section and made of cast steel, the upper one cylindrical and of cast iron. The lower drum is divided into three compartments, two of which are provided for water, the third being for superheated steam. The outer and lower compartment is connected with the upper drum by two large return pipes. It is also connected with the intermediate compartment of the same drum by U-shaped tubes. The feed-water enters the lower compartment, is heated in passing through the tubes, and rises to the upper drum; the steam thus formed is returned from the upper drum to the third drum in the lower drum, where it is superheated and from which it is taken to the motor. Coke is used for fuel, being fed automatically from a bunker attached to the side of the boiler. The motor is a four-cylinder tandem compound, rated at 260 horse power when running at 650 revolutions per minute. Valves of the ordinary D-type are used, operated through a Stephenson link motion. The car is capable of maintaining a speed of about 56 miles per hour, and it is claimed that the cost of operation per train mile is about 7 cents. Other types of motor cars are used in Europe, the principal difference being in the type of boiler used.