trains running at high rates of speed because of the danger arising from damage to the track and bridges, due to the hammer blow.

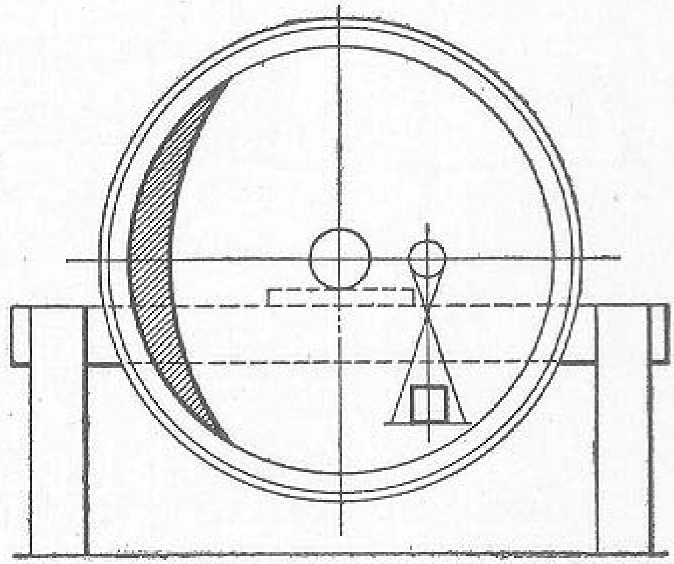

Fig. 74. Diagram Showing Method of Counterbalancing Driving Wheels.

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

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

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

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

TABLE XIV

Forged Steel Billets

(Standard Sizes)

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

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

TABLE XV

Hydraulic Pressures Used in Mounting Axles

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

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

TABLE XVI

Hydraulic Pressures Used in Mounting Crank-Pins

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

Locomotive Frames. Among other details of importance in the construction of a locomotive, none is more important than the frame. The frame is the supporting element and the tie bar that connects all the various moving and fixed parts. Its present form and proportions are due most largely to development rather than to pure design. It would be extremely difficult to analyze all the various forces to which the frames are subjected. There are two principal classes of locomotive frames, namely, the *single front rail* and the *double front rail*. The single front rail is illustrated in Fig. 75.

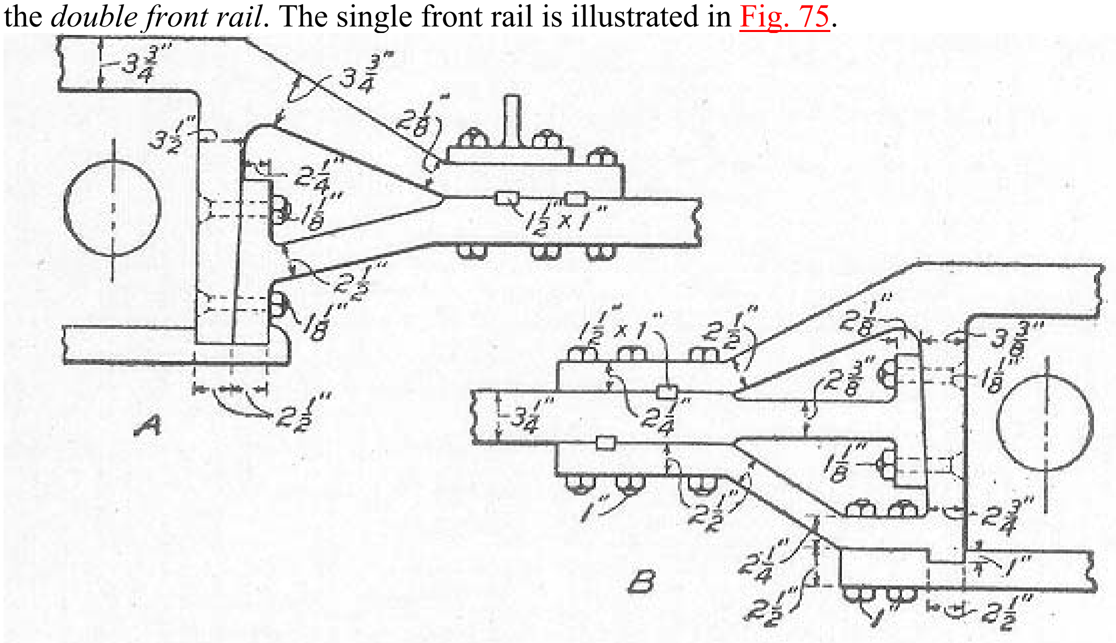

Fig. 75. Single Front Rail Locomotive Frames.

At first the joint between the main frame and the front rail was made as shown at *A* in Fig. 75. The rear end of the front rail was bent downward with a T-foot formed thereon by means of which it was connected to the main frame. The top member of the main frame was bent down and extended forward and connected to the front rail by means of bolts and keys. The T-head was fastened to the pedestal by two countersunk bolts. As locomotives grew in size, much trouble was experienced due to the countersunk bolts becoming loose or breaking. To overcome this difficulty, the form of joint shown in *B*, Fig. 75, was developed. Here the pedestal had a member welded to it which extended forward and upward to meet the front rail. The top member extended outward and downward as before. The front rail fitted between these two members and had a foot which rested against the pedestal. This latter form was used for many years, being changed in details considerably but retaining the same general arrangement. These forms of single bar frames continued to be used for many years and are employed at the present time for light locomotives. When the heavier types of locomotives, such as the Consolidation made their advent, it became necessary to improve the design of the frame. To meet this necessity, the double front rail frame was developed. Fig. 76 illustrates one of the earlier forms of this frame.

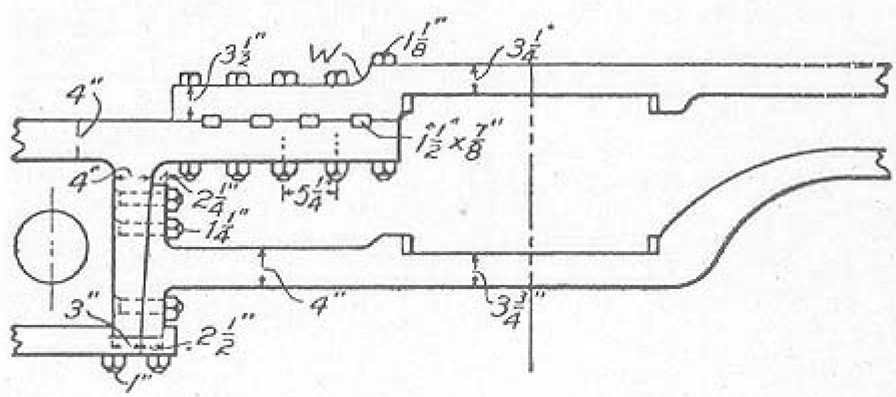

Fig. 76. Early Form of Double Front Rail Frame.

The top rail was placed upon and securely bolted to the top bar of the main frame and the lower front rail was fastened to the pedestal by means of a T-foot with countersunk bolts. The same difficulty was experienced with this design as with the first form of the single front rail type, namely, the breaking of the bolts fastening the lower bar to the pedestal. This led to experiments being tried which resulted in many stages of advancement until a heavy and serviceable design was developed, as shown in Fig. 77.

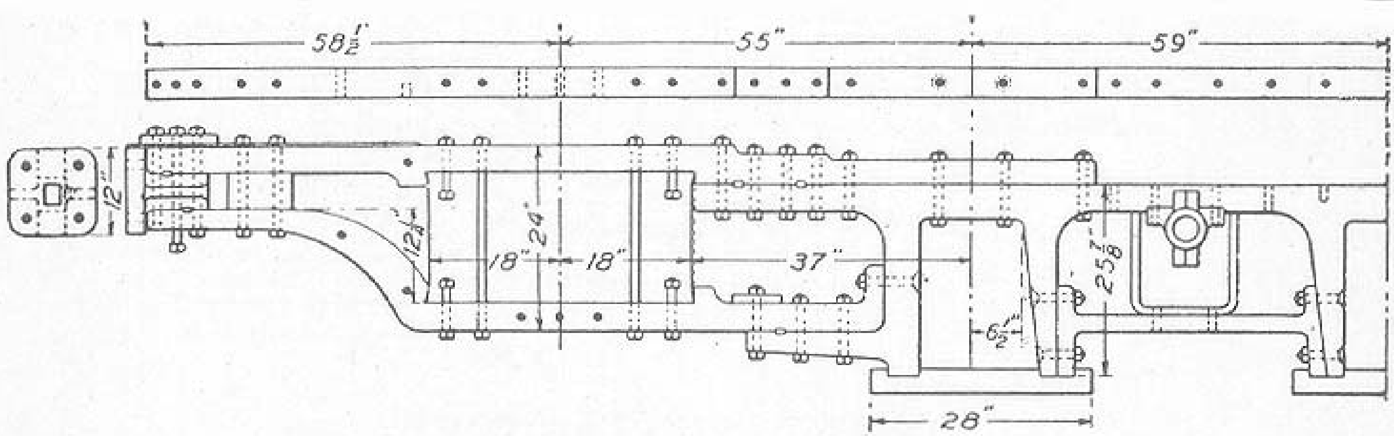

Fig. 77. Heavy Form of Double Front Rail Frame.

In this design the pedestal has a bar welded to it on which the lower front rail rests and to which it is connected by means of bolts and keys. The top front rail rests on top of the top main frame and extends back beyond the pedestal, thus giving room for the use of more bolts. The design shown in Fig. 77 is the one largely used on all heavy locomotives, it being slightly changed in detail for the various types. In addition to the two general types of bar locomotive frames which are made of wrought iron or mild steel, a number of cast-steel frames are being used. The general make-up of the cast-steel frame does not differ materially from that of the wrought iron except in the cross-section of the bars. The bar frame is rectangular or square in cross-section whereas the sections of cast-steel frames are usually made in the form of an **I**.

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

The Piston and Rods. The pistons of locomotives vary greatly in details of construction but the general idea is the same in all cases. Since the pistons receive all the power the locomotive delivers, they must be strongly constructed and steam tight. All pistons consist of a metal disk mounted on a piston rod which has grooves on the outer edges for properly holding the packing rings. The pistons are commonly made of cast iron, but where great strength is required, steel is now being used. Fig. 79 illustrates the present tendency in design. The cylindrical plate is made of cast-steel and the packing rings, two in number, are made of cast iron. The packing rings are of the snap ring type and are free to move in the grooves.

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

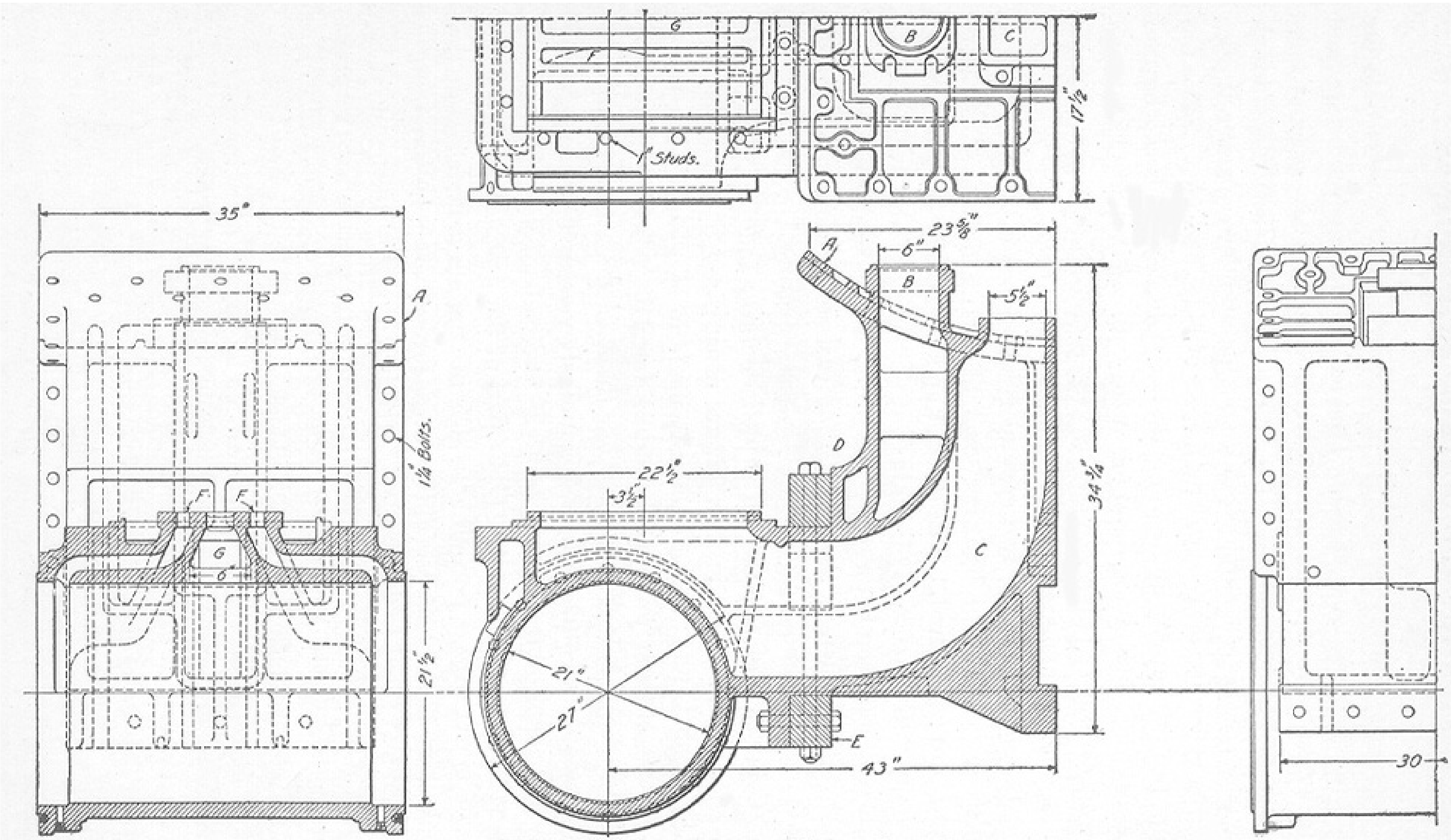

Fig. 78. Cylinder and Saddle of Simple Locomotive.

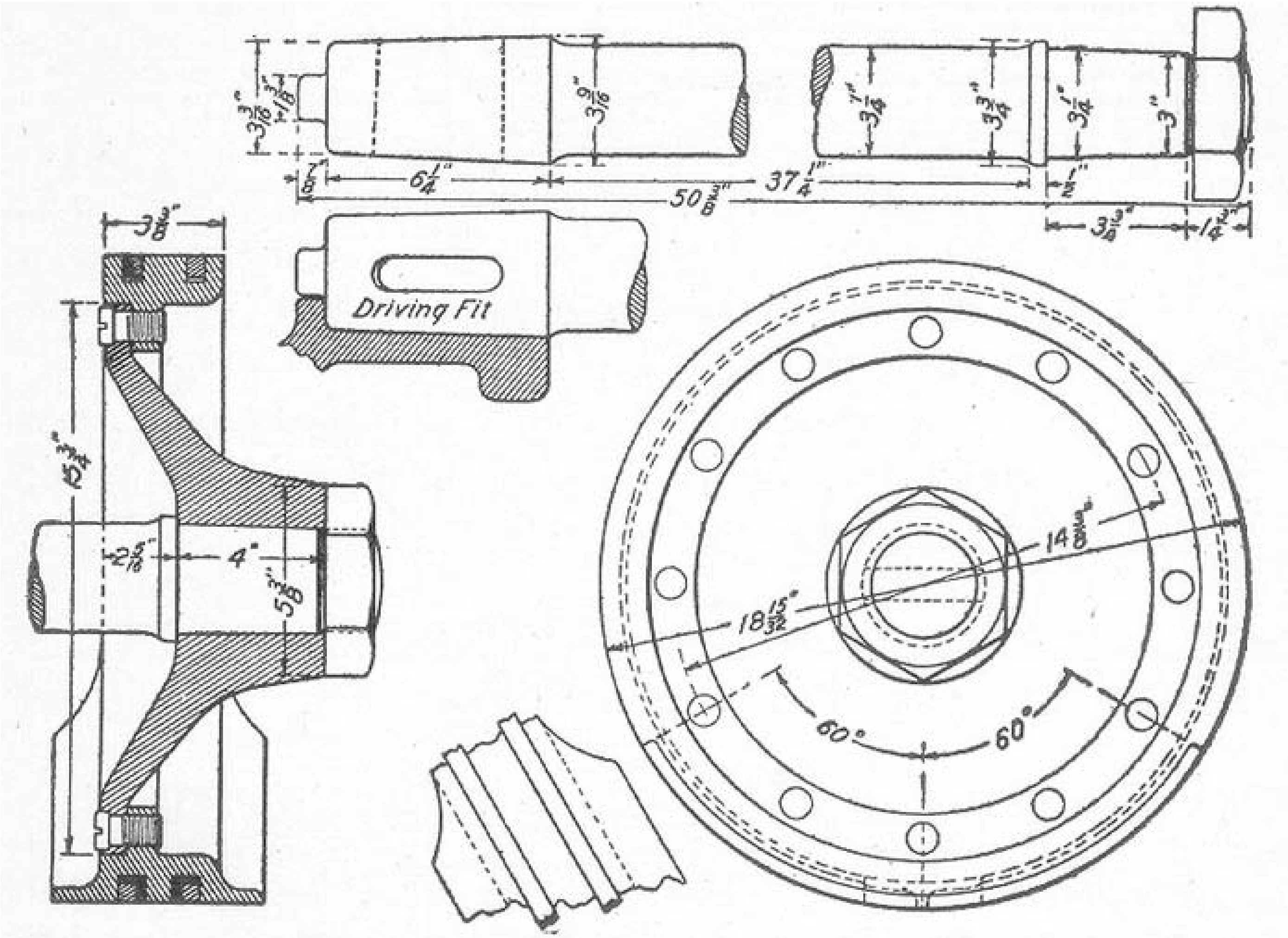

Fig. 79. Piston and Rods of Modern Locomotives.

Crossheads and Guides. A variety of forms of crossheads and guides are now found in use on locomotives, two of the most common of which are illustrated in Fig. 80 and Fig. 81. The form illustrated in Fig. 80 is known as the *4-bar guide* and that shown in Fig. 81, as the *2-bar guide*. The form used depends largely on the type of engine. The 4-bar guide now used on light engines consists of four bars *A* which form the guide with the crosshead *B* between them. The bars are usually made of steel and the crosshead of cast-steel having babbitted wearing surfaces. The 4-bars *A* are bolted to the guide blocks *C* and *D* which are held by the back cylinder head and the guide yoke *E*, respectively. The guide yoke *E* is made of steel, extends from one side of the locomotive to the other, is securely bolted to both frames, and serves to hold the rear end of both guides. There is usually a very strong brace connected to the guide yoke which is riveted to the boiler. The wrist pin used in the crosshead of the 4-bar type is cast solid with the crosshead.

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

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

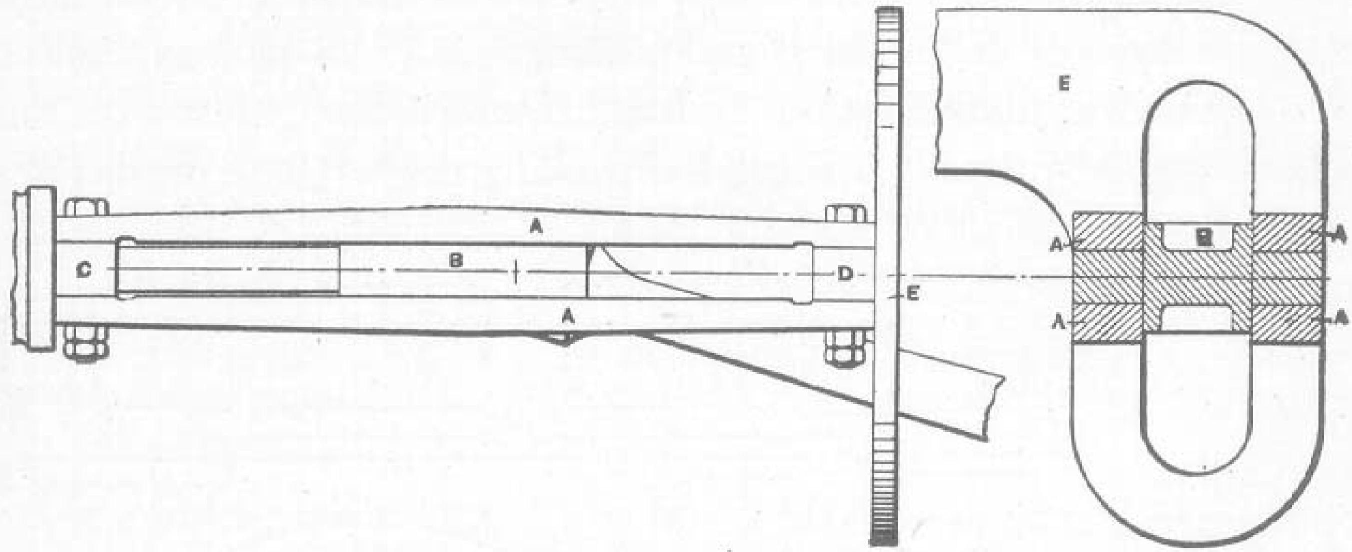

Fig. 80. Common Form of Crosshead and Guides.

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

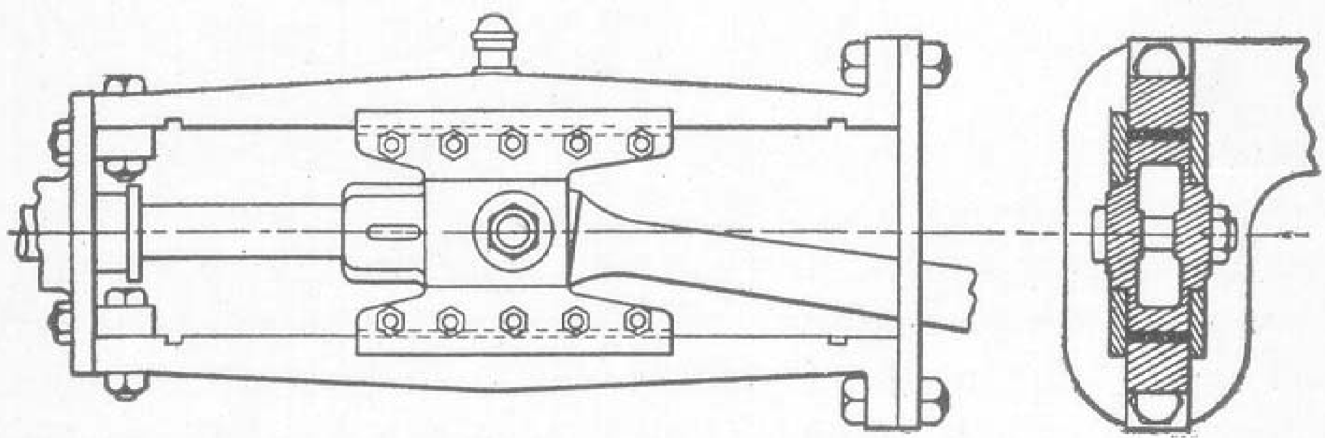

Fig. 81. Common Form of Crosshead and Guides.

Connecting or Main Rods. Connecting or main rods are made of steel, the section of which is that of an **I**. The **I**-section gives the greatest strength with a minimum weight of metal. Fig. 82 illustrates modern practice in the design of connecting rods for a heavy locomotive. The design for passenger locomotives is quite similar to that shown. Aside from the general dimensions and weight of the rod, there are to be noted some important details in the manner in which the brasses are held and the means provided for adjusting them. The older forms of rods had a stub end at the crank pin end with a strap bolted to the rod. A key was used in adjusting the brasses. With the building of locomotives of greater capacity, this construction was found to be weak. The connecting rod shown in Fig. 82 has passed through several stages in the process of its development. The crank end is slotted, the brasses being fitted between the upper and lower jaw. The brasses are held in place by a heavy cotter *A* and a key *B*. The cotter is made in a form which prevents the spread of the jaws *C* and *D*. The adjustment of the brasses is made by means of the key *B* in the usual way. The brasses at the crosshead end are adjusted by the wedge *E*. The oil cups are forged solidly on the rod.

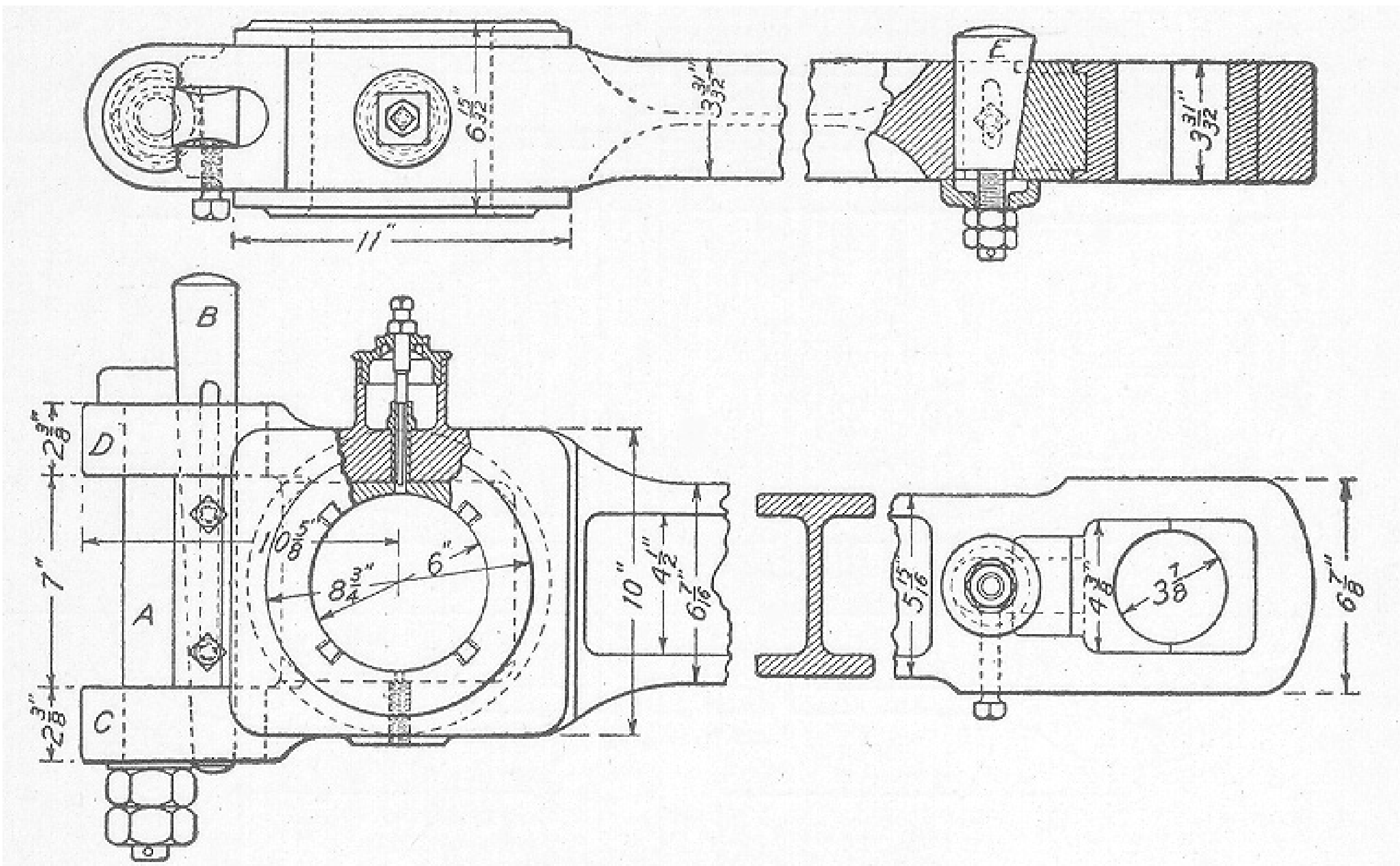

Fig. 82. Connecting Rod Details.

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

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

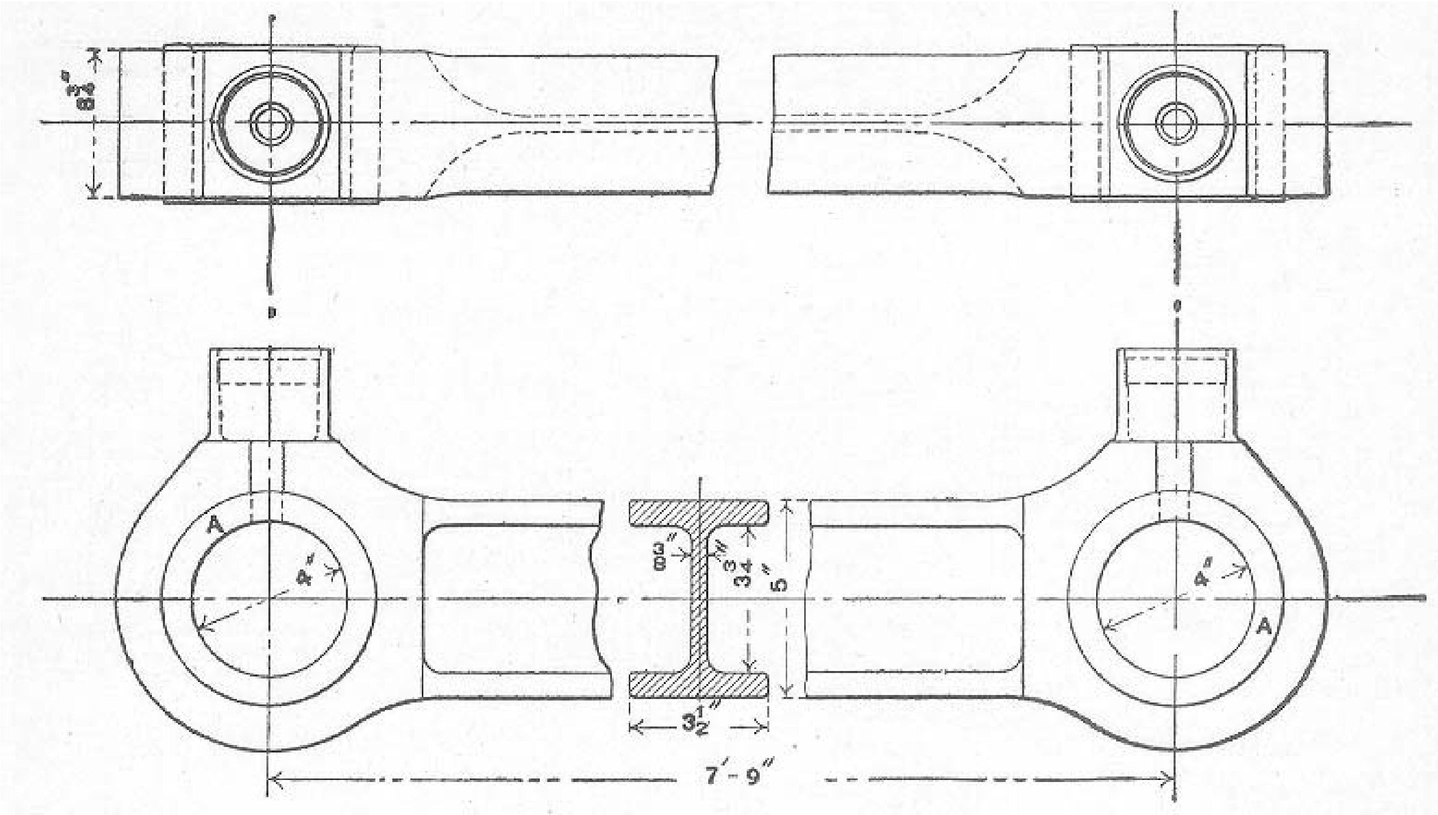

Fig. 83. Side Rod.

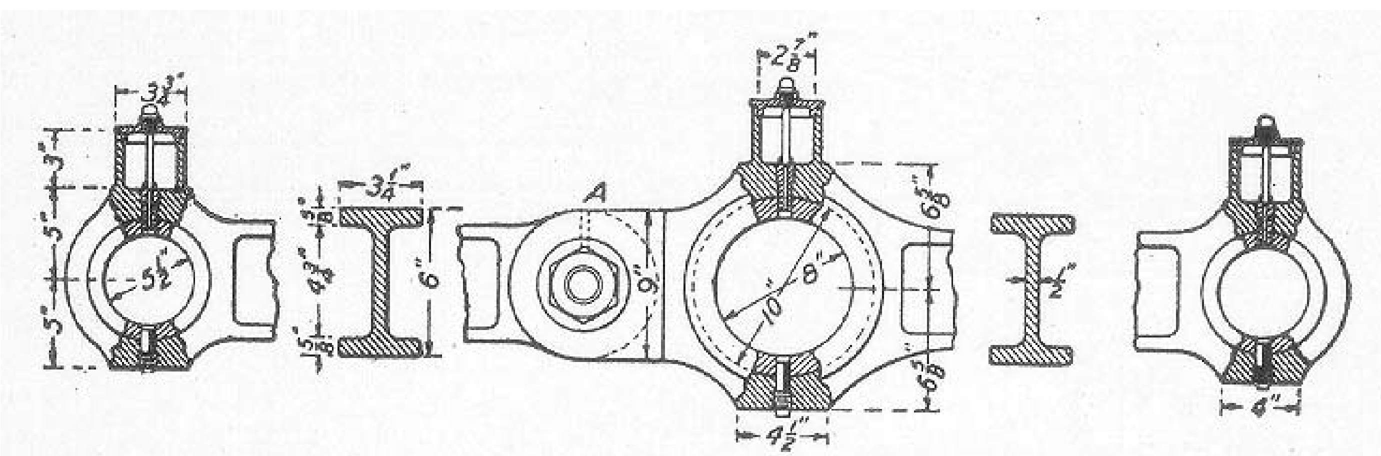

Fig. 84. Hinged Joint for Use with Locomotives Having More Than Two Pairs of Drivers.

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

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

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

where

R = length of rigid wheel base of engine in feet
D = distance in feet from front flanged driver axle to center of truck
X = length in feet of radius bar

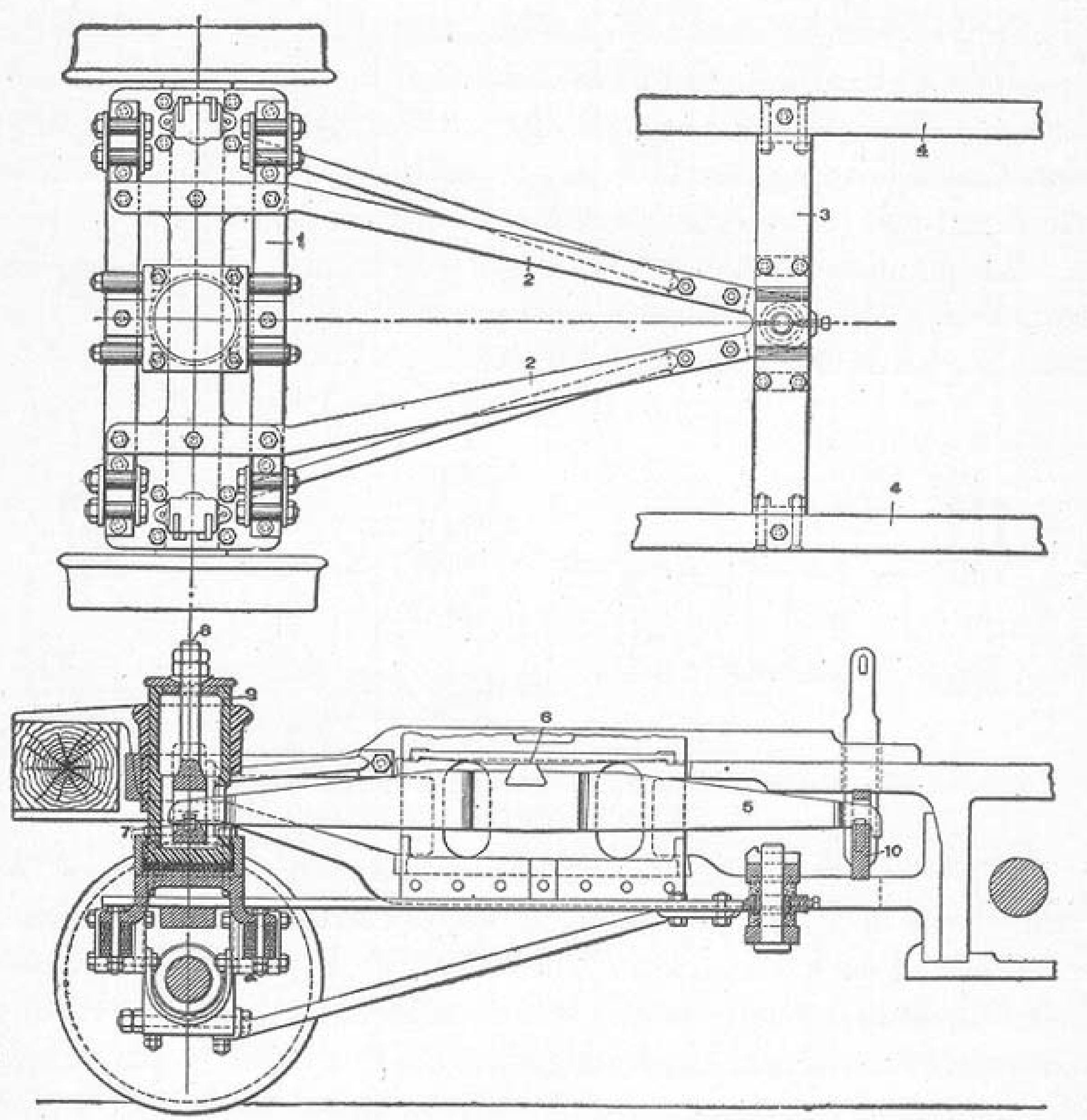

Fig. 85. Pony or Two-Wheeled Truck.

The usual method of applying the weight to a pony truck is by means of the equalizing lever, 5. The fulcrum, 6, of this equalizing lever is located under the cylinders where the weight is applied. The front end of the equalizing lever is carried by the pin, 8, which, in turn, is carried by the sleeve, 9, and transmits the load to the center plate while the rear end of the lever is supported by means of the cross lever, 10, which is carried by the driving wheel springs.

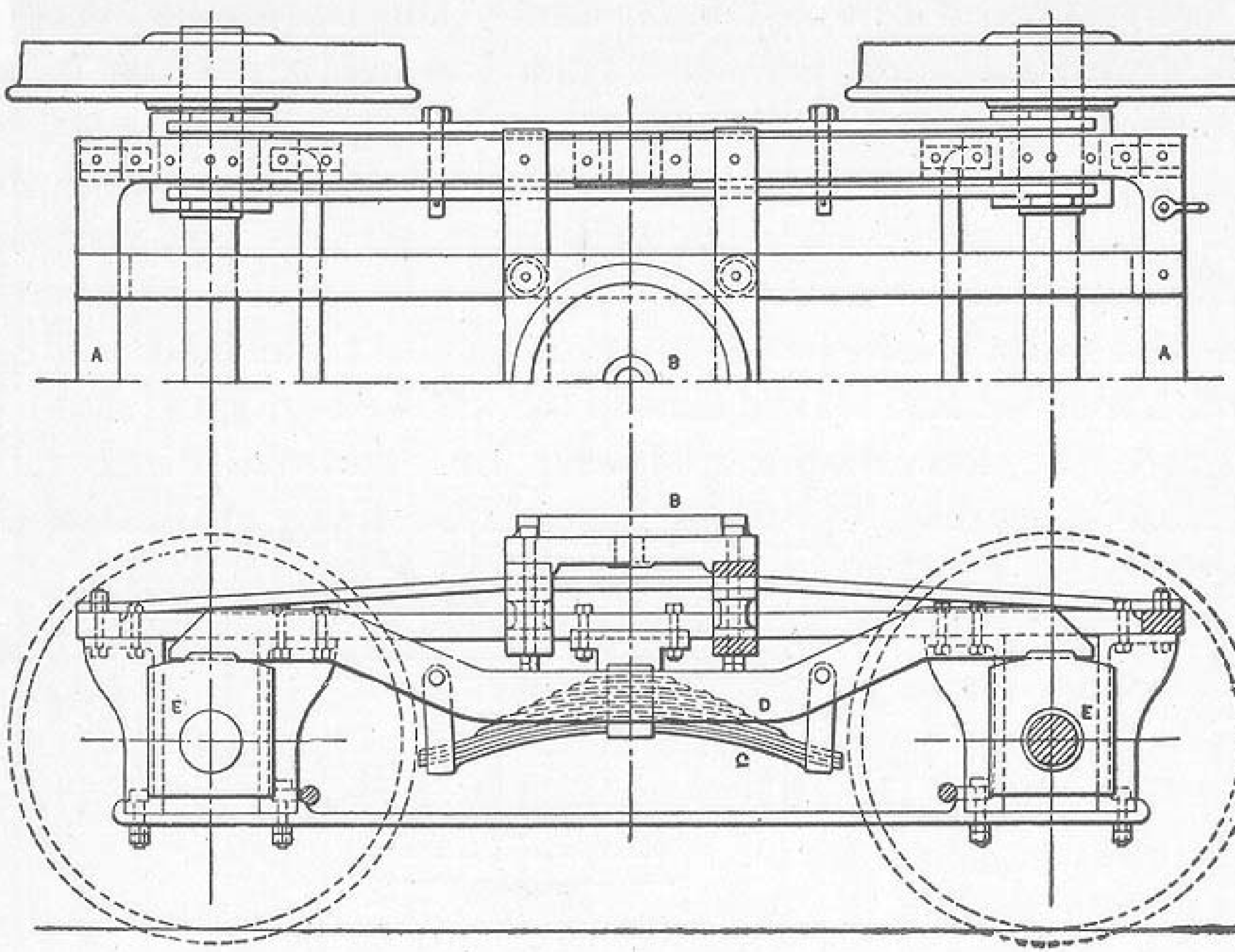

Fig. 86. Four-Wheeled Truck.

The four-wheeled truck is constructed in a number of different ways, one of which is illustrated in Fig. 86. The construction is simple, consisting of a rectangular frame, *A*, carrying a center plate, *B*. As in the case of the pony truck, the journals are inside of the wheels. The truck, which is pivoted on the center plate, carries the front-end of the locomotive and serves as a guide for the other wheels of the locomotive.

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

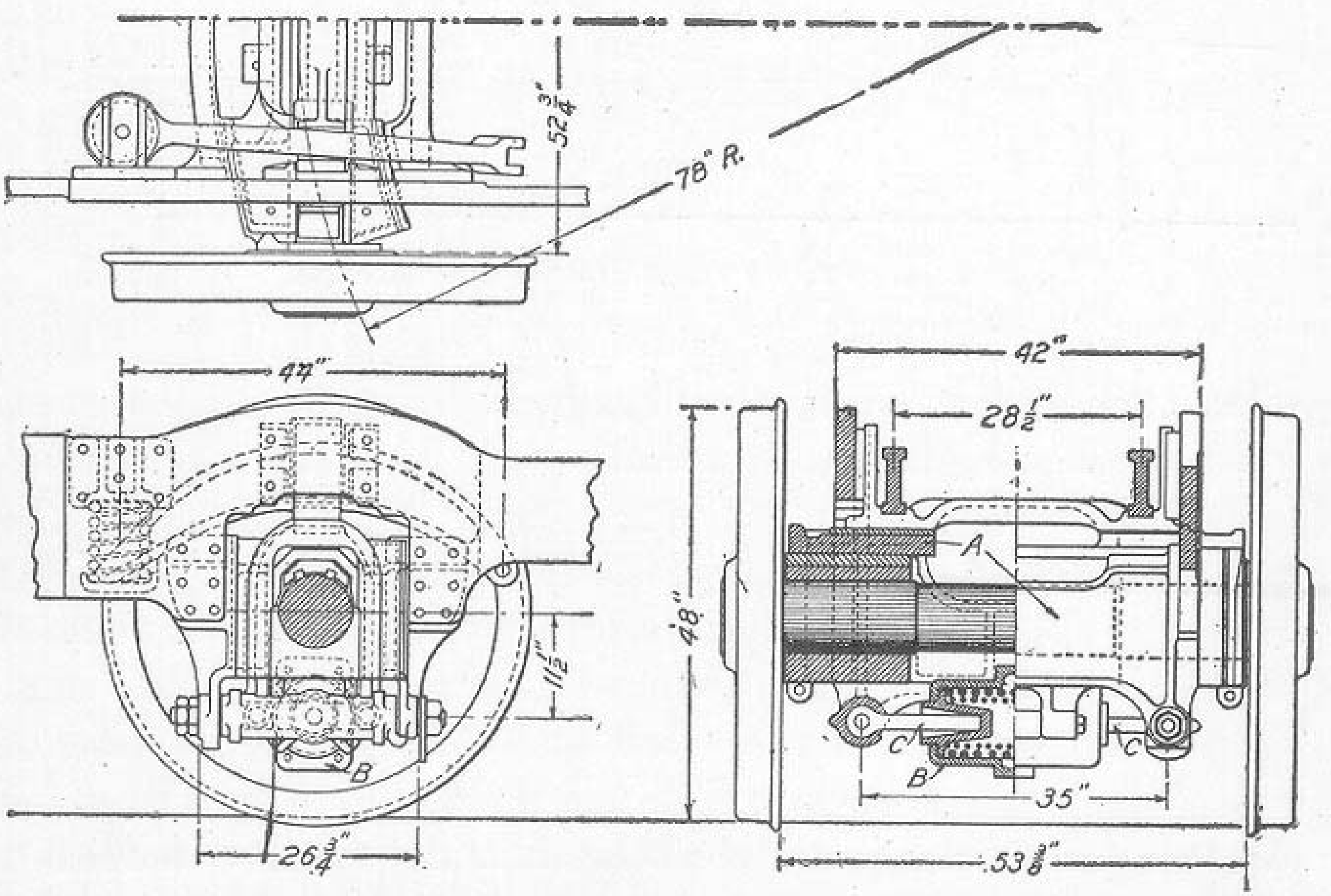

Fig. 87. Trailing Truck with Inside Bearings.

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

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

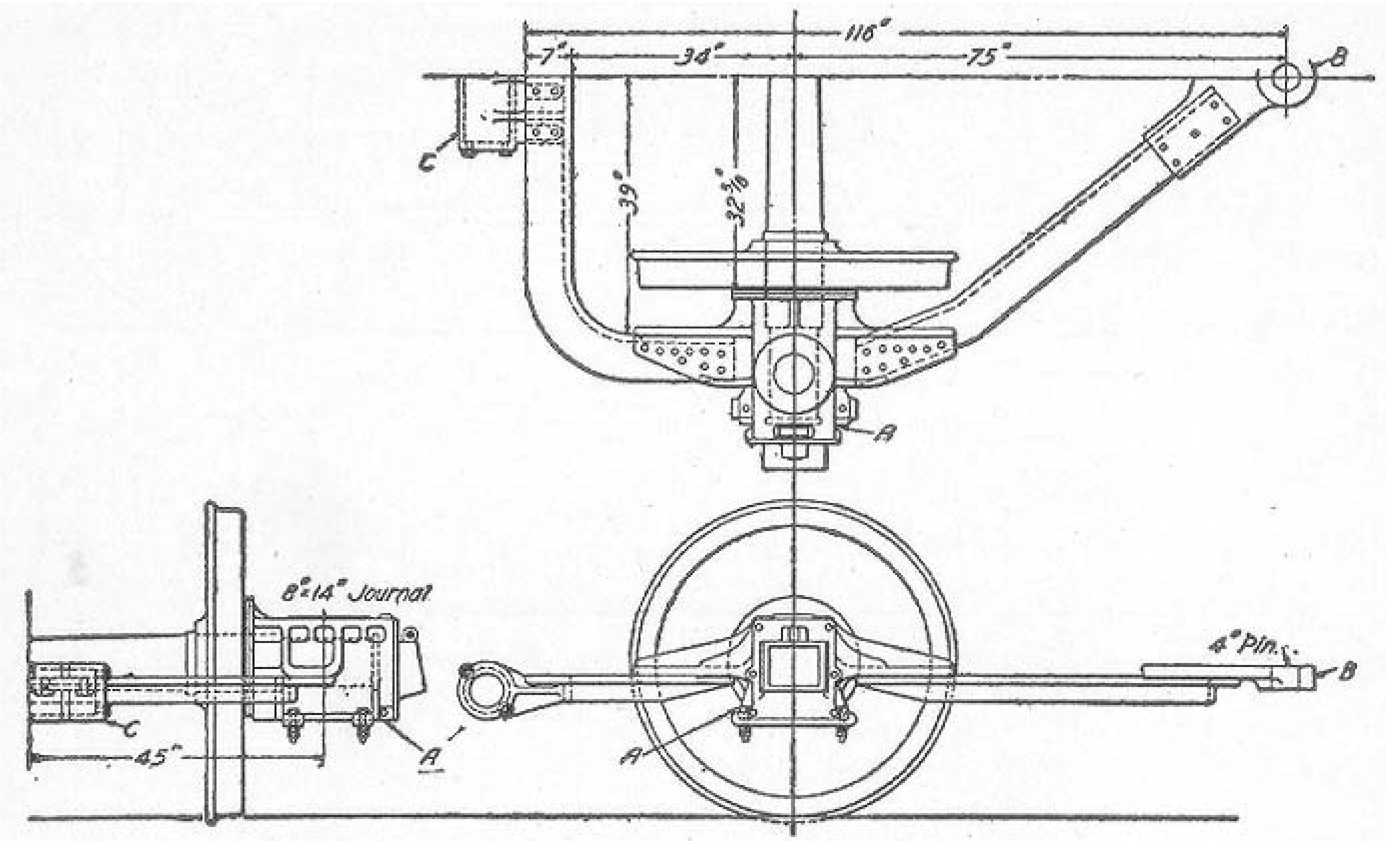

Fig. 88. Trailing Truck with Outside Bearings.

The Tender. The tender of a locomotive is used to carry the coal and water supply for the boiler. It is carried on two four-wheeled trucks having a frame work of wood or steel, the latter being mostly used at the present time. This frame supports the tank in which the water is stored, which, in the case of passenger and freight locomotives, is usually constructed in the shape of the letter U, the open end of which faces the fire door. The open space between the legs of the U is used for coal storage. The water is drawn from the tank near the two front corners. In these two front corners are placed tank valves which are connected by means of the tank hose and pipes to the two injectors. Near the back end of the tank is a manhole which permits a man to enter the inside to make repairs. This opening is also used in filling the tank at water towers. Tanks are made of open hearth steel, usually about ¼ of an inch in thickness, the sheets being carefully riveted together to prevent leaks. The interior of the tank is well braced and contains baffle plates which prevent the water from surging back and forth, due to curves and shocks in the train itself. The tank is firmly bolted to the frame.

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

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

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

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

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

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

1. It should be able to handle any desired quantity of coal and at the same time call for less physical effort on the part of the fireman than is required in hand firing.
2. It should be able to successfully handle any grade of coal.
3. It should be able to maintain full steam pressure under all conditions.
4. It should not become inoperative under ordinary conditions of service.
5. Its construction should permit of hand firing to meet emergency conditions.

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

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

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

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

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

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

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

DESIGN OF PARTS OF THE ENGINE

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

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

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

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

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

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

d = the diameter of axle in inches

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

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

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

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

for the main axle, and

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

for the back axle.

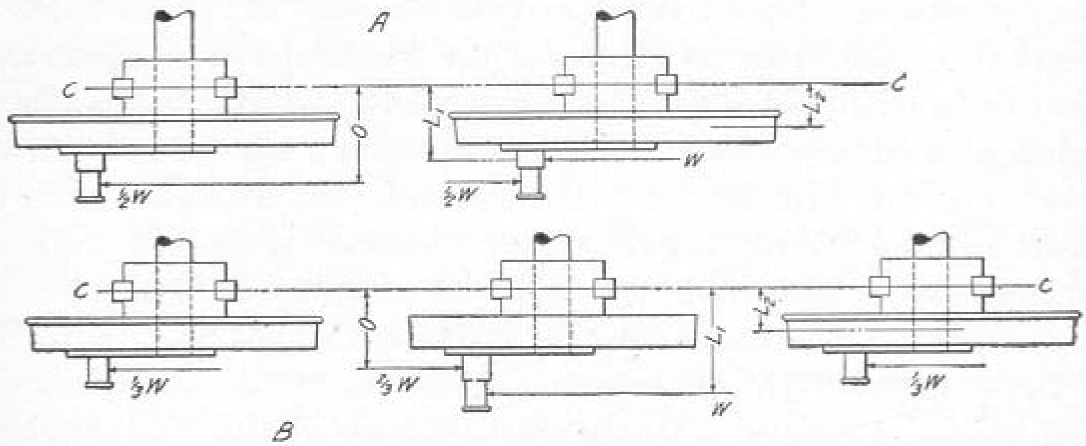

Fig 89. Force Diagram for Drivers.

Let

W_1 = the dead load in pounds on each journal

and

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

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

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

Let

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

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

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

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

Let

D = the diameter of drivers in inches

F = the centrifugal force in pounds

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

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

r = the radius of curvature of the track in feet

v = the velocity of the locomotive in feet per second

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

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

where

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

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

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

where

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

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

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

TABLE XVII

Fiber Stresses

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

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

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

Solution.

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

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

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

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

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

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

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

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

$$= 10700 \text{ pounds}$$

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

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

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

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

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

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

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

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

Therefore,

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

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

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

Therefore, an 8¾ steel axle is large enough for an 8-wheel passenger locomotive since the allowable fiber stress of 13,000 pounds per square inch is not exceeded.

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

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

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

Let

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

S = the safe fiber stress in pounds per square inch

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

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

P_1 = the force in pounds transmitted to the side rod

d = the diameter of crank pin in inches

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

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

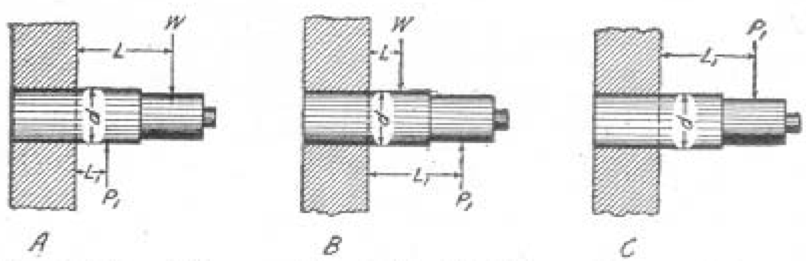

Fig. 90. Action of Force on Crank Pins in Different Types of Locomotives.

Having given the above conditions, we may write

$$M = W\,L - P_1\,L_1$$

and

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

From this last equation

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

Finally, substituting the value of M we get

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

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

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

and for a 10-wheeled locomotive it is

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

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

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

$$M = P_1 L_1$$

and finally

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

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

TABLE XVIII
Working Stress for Crank Pins

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

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

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

Considering tension alone

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

and considering buckling

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

where

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

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

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

$$d = .0108 \times 20 \sqrt{190}$$
$$= 2.98 \text{ inches}$$

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

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

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

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

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

Let

P = the thrust on the piston or the area of the piston in square inches multiplied by the boiler pressure in pounds per inch
A = the area in square inches of the section of the frame at the top of the pedestal
B = the area in square inches of the section of the frame at the rail between the pedestals
C = the area in square inches of the section of the lower frame between the pedestals

Then

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

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

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

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

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

where

t = thickness of cylinder wall in inches
p = pressure in pounds per square inch
d = diameter of cylinder in inches
f = safe fiber stress which for cast iron is usually taken at 1500 pounds per square inch

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

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

where

T = the thickness of the cylinder head in inches
p = boiler pressure in pounds per square inch
d = diameter of stud bolt circle

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

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

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

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

where

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

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

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

from which

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

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

Solution.

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

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

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

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

where

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

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

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

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

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

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

where

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

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

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

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

in which

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

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

$$R' = 0.38\,M$$

in which

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

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

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

in which

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

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

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

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

in which

v = the speed in miles per hour attained in one mile when starting from rest, being uniformly accelerated
R''' = resistance in pounds per net ton due to acceleration

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

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

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

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

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

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

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

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

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

Within ordinary limits, the following formula gives very accurate results

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

where

T = number of tons including engine, which can be hauled over a grade with velocities of V and v
d = diameter of cylinder in inches
L = length of stroke in inches
p_1, = mean effective pressure in pounds per square inch
D = diameter of driver in inches.
R' = resistance in pounds per ton on a level track due to friction, air curves, and velocity, which may be taken at 8 pounds per ton
a = grade in feet per mile
l = length of grade in feet
V = velocity in miles per hour at foot of grade
v = velocity in miles per hour at top of grade

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

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

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

There is considerable difference of opinion regarding the allowance which should be made for the conditions of weather, etc. The following is a fair allowance which has been found to give satisfactory results in practice: Seven per cent reduction for frosty or wet rails; fifteen per cent reduction for from freezing to zero temperature; and twenty per cent reduction for from zero to twenty degrees below. The use of pushing or helping engines over the most difficult grades of an undulating track will increase the train load and thus reduce the cost of transportation.

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

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

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

It should be so designed that it can neither be tampered with nor get out of order. It must act promptly and efficiently and not be affected by the motion of the locomotive. These conditions are all fulfilled in the type of valve shown in section in Fig. 91. In this design, the valve *a* rests on the seat *b b* and is held down by a spindle *c*, the lower end of which rests on the bottom of a hole in the valve *a*. A helical spring *d* tests on a collar on the spindle. The pressure on the spindle is regulated by screwing the collar *e* up or down. The valve seat *b b* may be rounded or straight. Outside of the valve seat there is a projection *f*, beneath which a groove *g* is cut in the casing. When the valve lifts, this groove is filled with steam which presses against that portion of the valve outside of the seat, and, by thus increasing the effective area of the valve, causes it to rise higher and to remain open longer than it otherwise would without this projection. The adjustment of the valve is usually made so that after opening, it will permit steam to escape until the pressure in the boiler is about 4 pounds below the normal pressure. The steam escaping through the small holes *h*, is muffled, thus avoiding great annoyance.

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

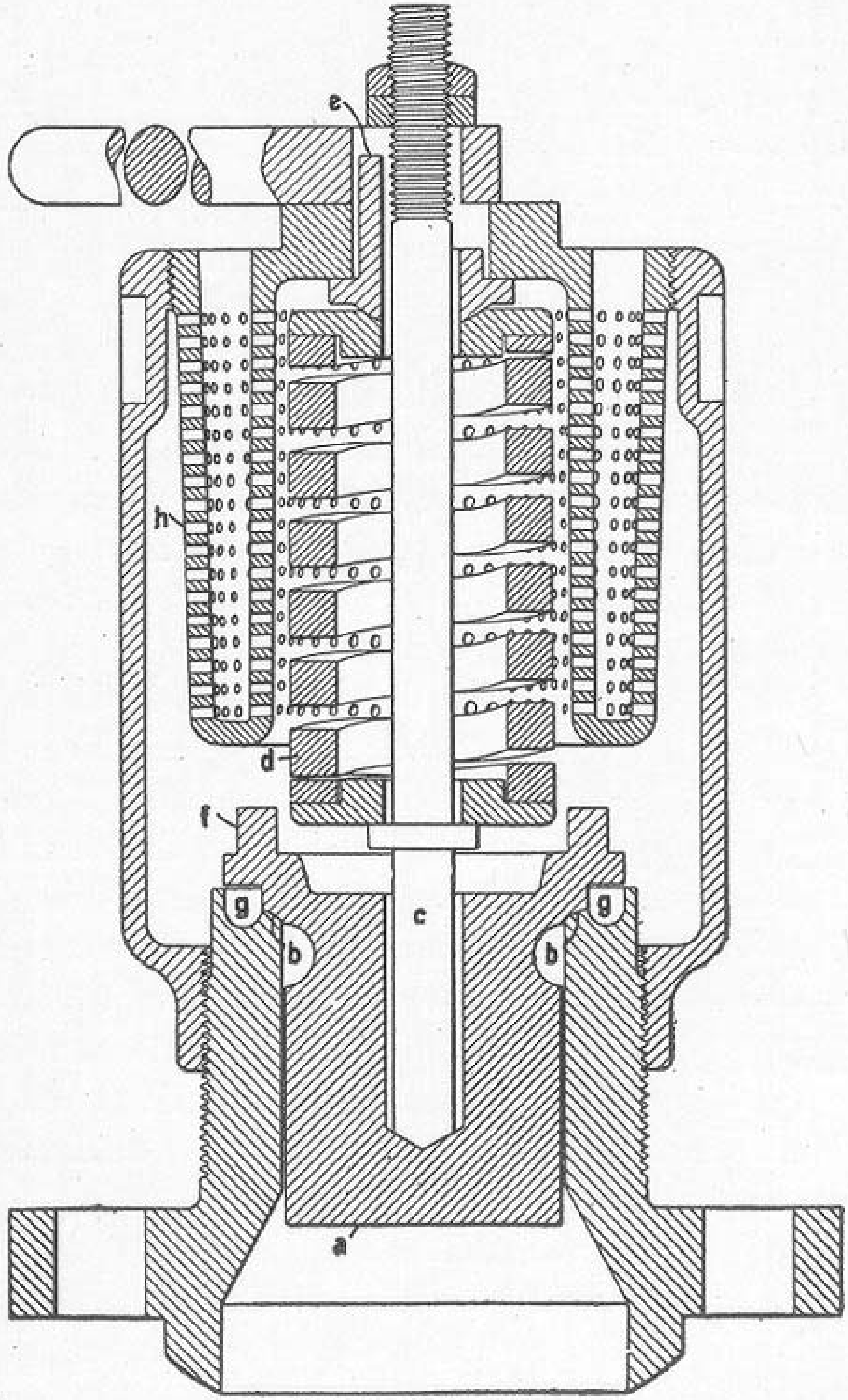

Fig. 91. Section of Safety Valve.

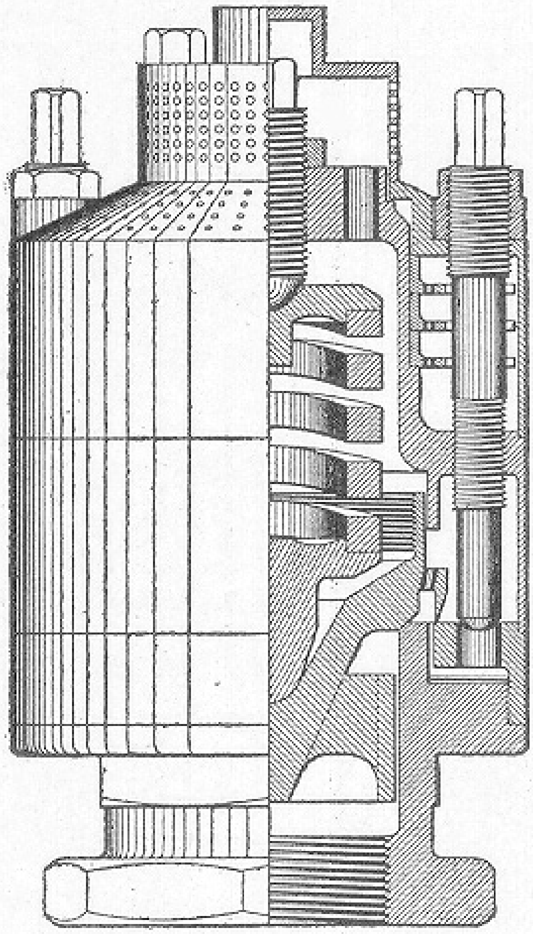

Fig. 92. Another Form of Safety Valve.

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

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

Sellers Injector. To operate this injector, the method of procedure is as follows: Draw starting lever, 33, slowly. If the water supply is hot, draw the lever about one inch and after the water is lifted, draw the lever out the entire distance. The cam lever, 34, must be in the position shown. To stop the injector, push the starting lever in. To regulate the amount of flow of water after the injector has been started, adjust the regulating handle, 41.

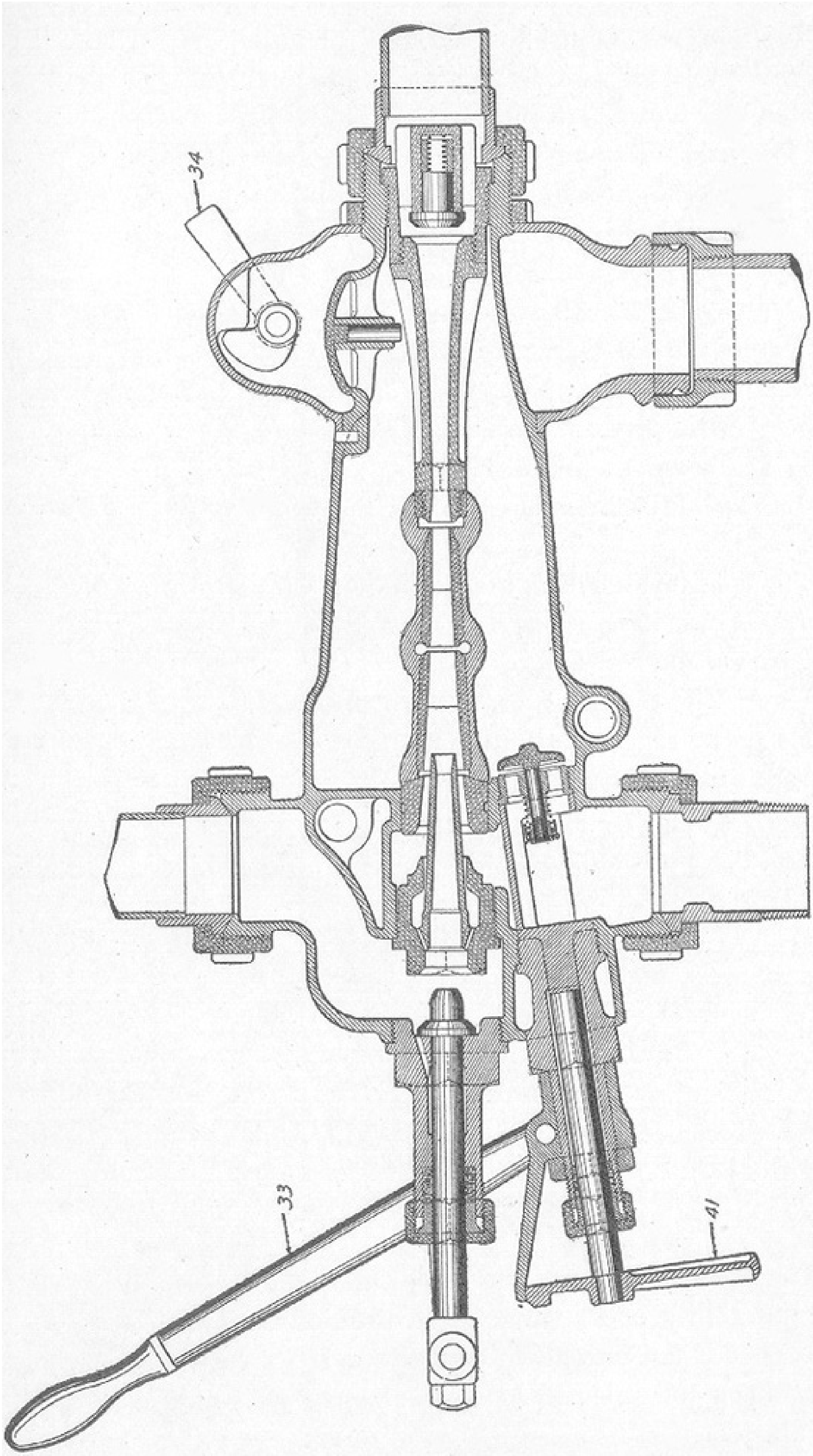

Fig. 93. Sellers Injector.

If it is desired to use the injector as a heater, place the cam lever, 34, in the rear position and pull the starting lever slowly.

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

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

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

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

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

All valves should be kept tight and all spindles kept tightly packed. When a pipe is attached to the overflow, it should be the size called for by the manufacturer.

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

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

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

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

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

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

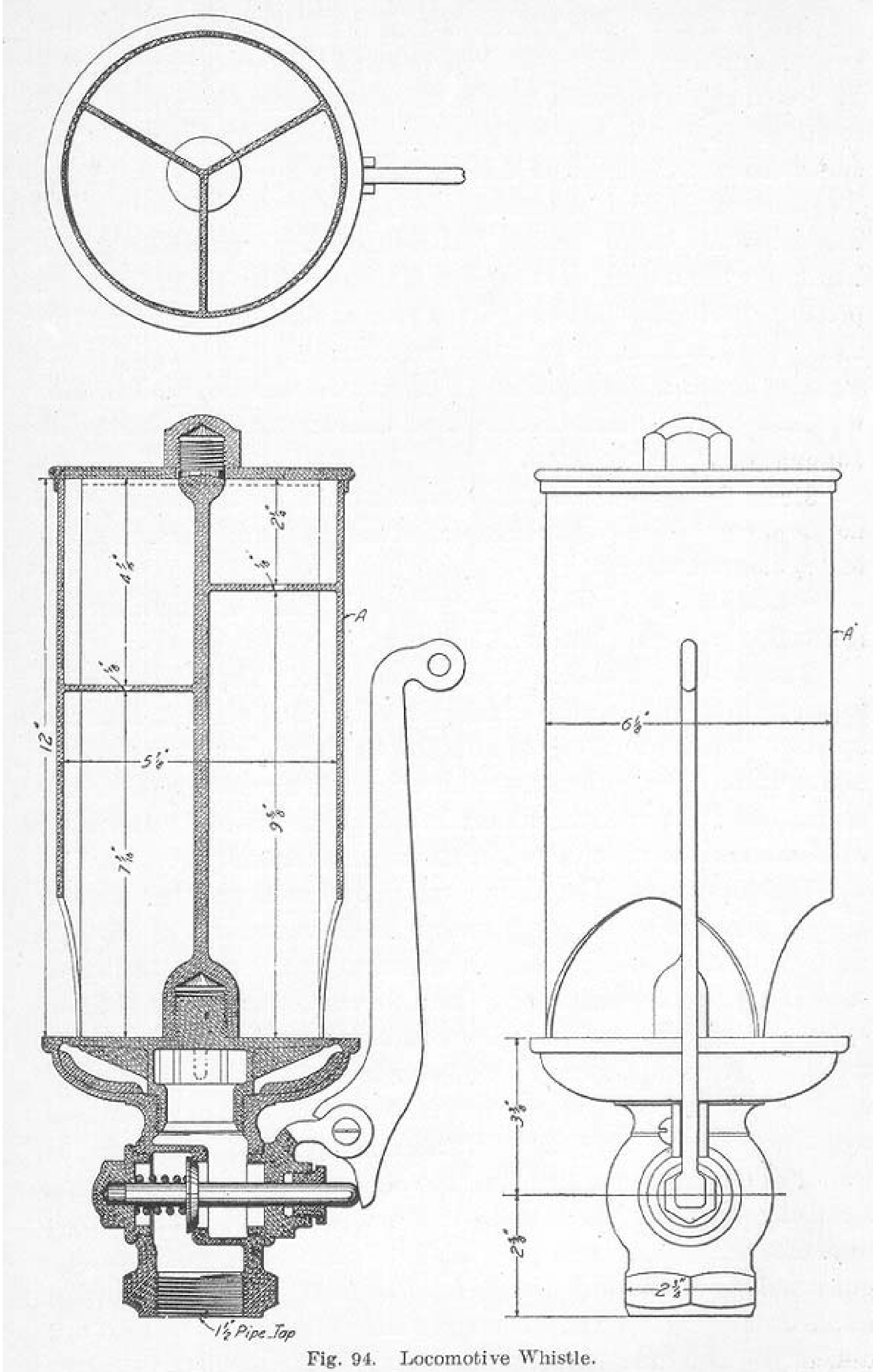

Fig. 94. Locomotive Whistle.

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

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

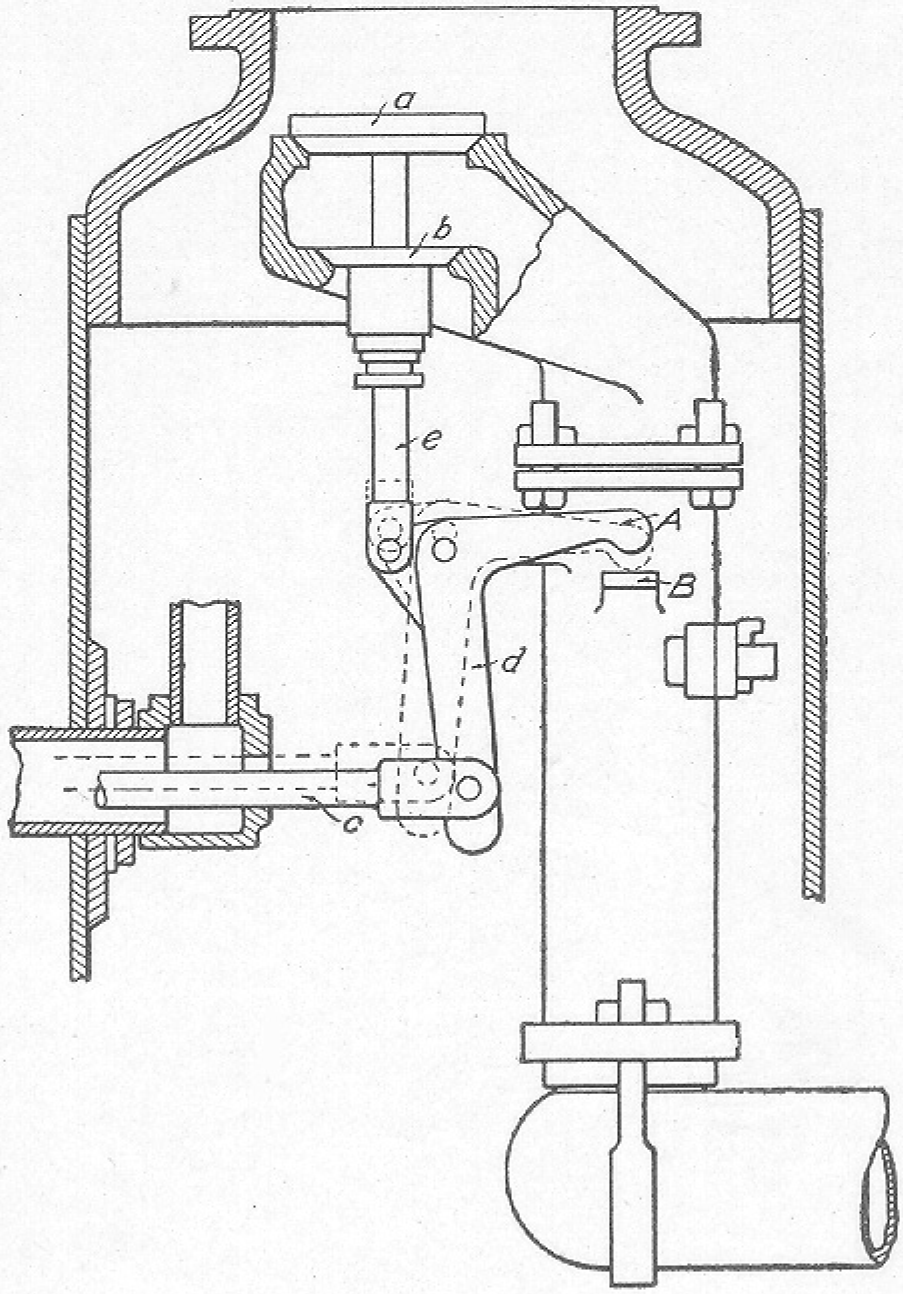

Fig. 95. Throttle Valve.

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

Throttle Valve. The throttle valve now in universal use is some form of a double-seated poppet valve, as illustrated in Fig. 95. In this type, two valves *a* and *b* are attached to a single stem, the upper valve being slightly the larger. The lower valve *b* is of such a diameter that it will just pass through the seat of the valve *a*. The steam, therefore, exerts a pressure on the lower face of *b* and the upper face of *a*. As the area of a is the greater, the resultant tendency is to hold the valve closed. The valve is, therefore, partially balanced. It will be difficult to open large throttle valves such as are now used on locomotives carrying high steam pressures, with the ordinary direct form of leverage. In such cases, it will be necessary to give a strong, quick jerk to the throttle lever before the valve can be moved from its seat. The arrangement of leverage shown in Fig. 95 obviates this difficulty. The rod *c* connects with a lever in the cab and coauxuliucates its movement to the bell crank *d*, whence it is carried by the stem *e* to the valve. The pivot of the bell crank is provided with a slotted hole. At the start, the length of the short arm is about 2¼ inches while the long arm is about 9½ inches. After the valve has been lifted from its seat and is free from excess pressure on *a*, the projecting arm *A* on the back of the bell crank comes in contact with the bracket *B* on the side of the throttle pipe and the bell crank takes the position shown by the dotted lines in the figure. The end of the projecting arm *A* then becomes the pivot and the length of the short arm of the lever is changed to 9½ inches and that of the long arm to about 11½ inches.

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

TABLE XIX
Dry Pipe Sizes

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

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

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

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

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

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

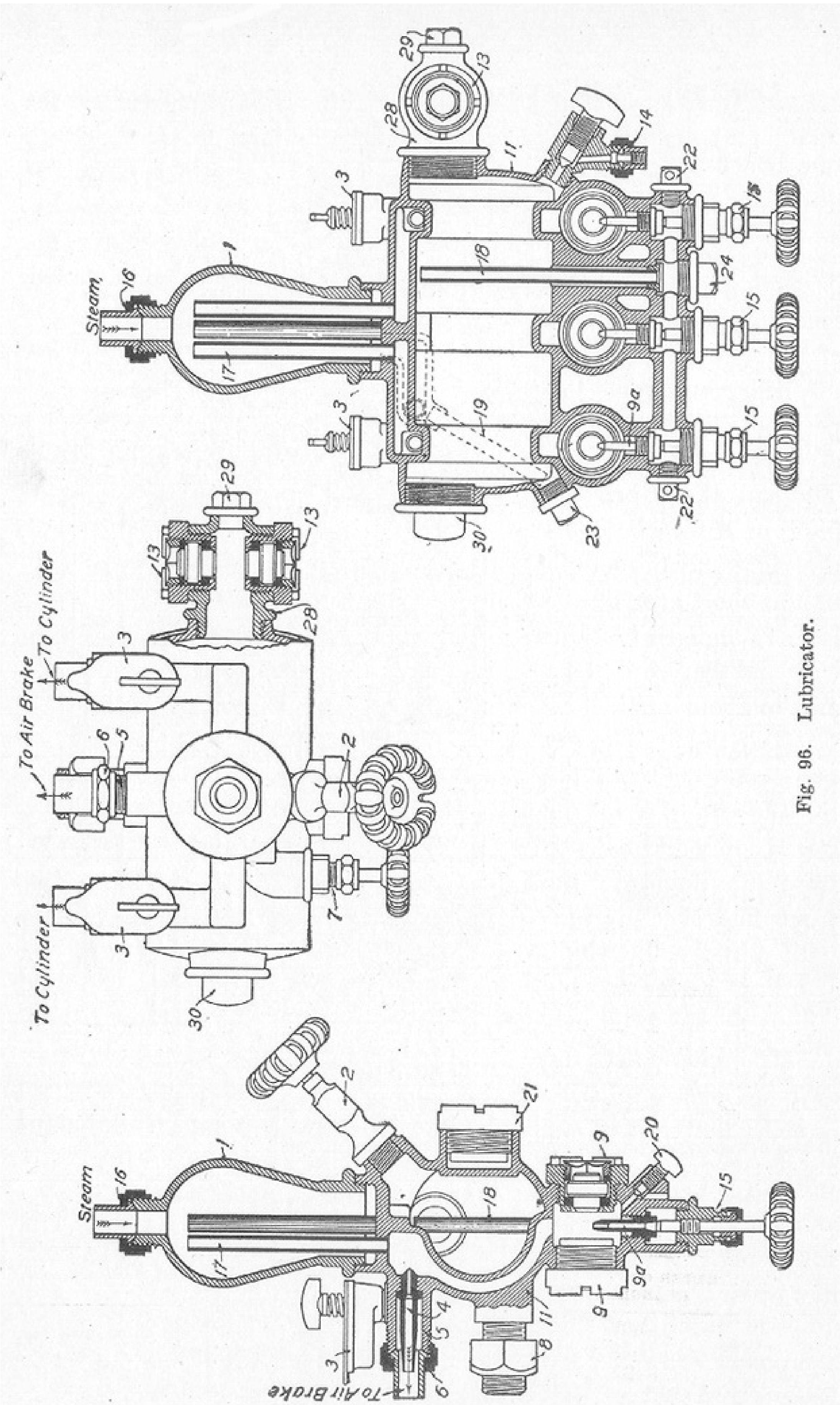

Fig. 96. Lubricator.

RAILWAY SIGNALING

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Red signifies danger and is a signal to stop.
Green signifies caution and is a signal to go slowly.
White signifies safety and is a signal to continue.
Green and *white* is a signal to be used to stop trains at flag stations for passengers or freight.
Blue is a signal to be used by car inspectors and repairers and signifies that the train or cars so protected must not be moved.

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

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

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

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

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

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

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

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

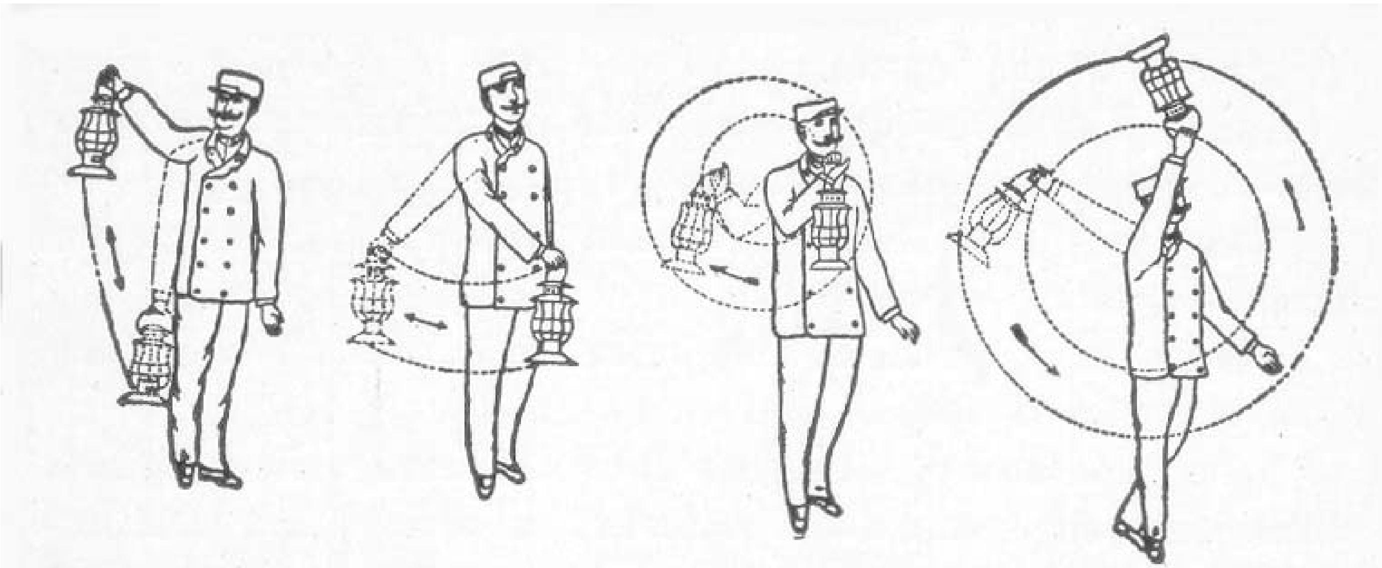

Fig. 97. Signal to Go Ahead.

Fig. 98. Signal to Stop.

Fig. 99. Signal to Back Up.

Fig. 100. Signal that Train has Parted.

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

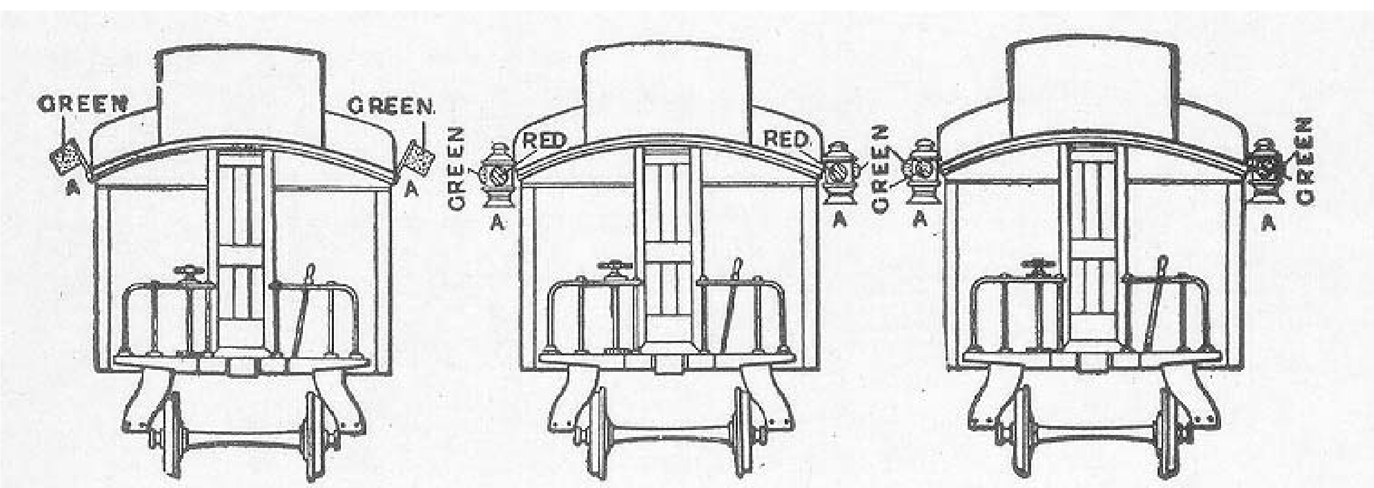

Fig. 101. Day Rear Signal.

Fig. 102. Night Rear Signal.

Fig. 103. Night Signal of a Clear Track.

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

When a train pulls out to pass or meet another train the red lights must be removed and green lights displayed as soon as the track is clear. Fig. 103, but the red lights must again be displayed before returning to its own track.

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

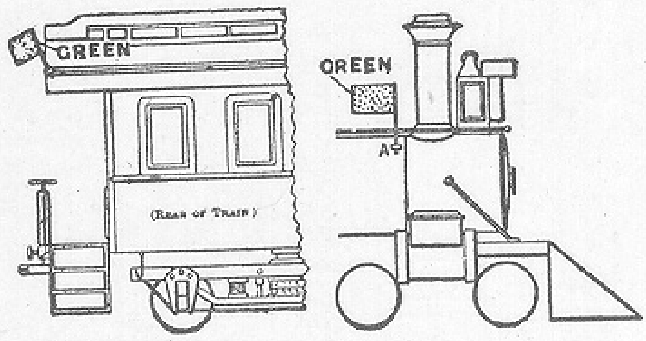

Fig. 104. Day Signal of a Train Behind.

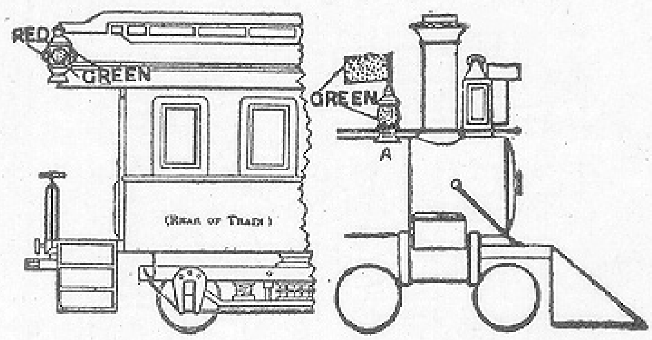

Fig. 105. Night Signal of a Train Behind.

Two green flags by day and night, Fig. 104, and in addition two green lights by night, Fig. 105, displayed in places provided for that purpose on the front of an engine denote that the train is followed by another train running on the same schedule and entitled to the same time table rights as the train carrying the signals.

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

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

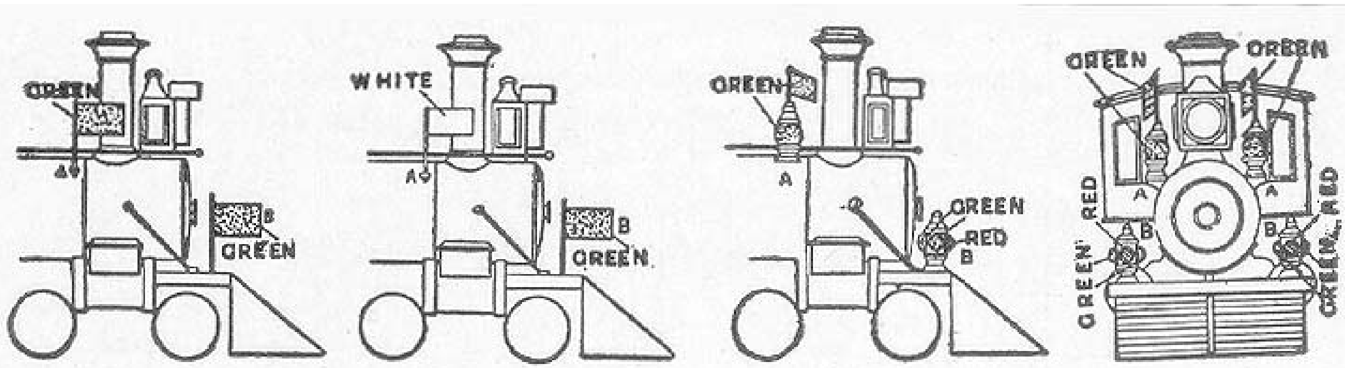

Fig. 106. Fig. 107. Fig. 108.
Signal of Train Behind or Locomotive Running Backward.

Two white flags by day and night. Fig. 109, and in addition two white lights by night. Fig. 110, displayed in places provided for that purpose on the front of an engine, denote that the train is an extra. These signals must be displayed by all extra trains but not by yard engines.

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

Fig. 108 shows the arrangement of flags and lights on a locomotive which is running backward by night without cars or pushing cars and carrying signals for a following train. There is a green flag and light at *A* and a combination light at *B*. The green light and flag at *A* serve as a classification signal. The combination light at *B* is a marker showing green on the side and the direction in which the engine is moving and red in the opposite direction.

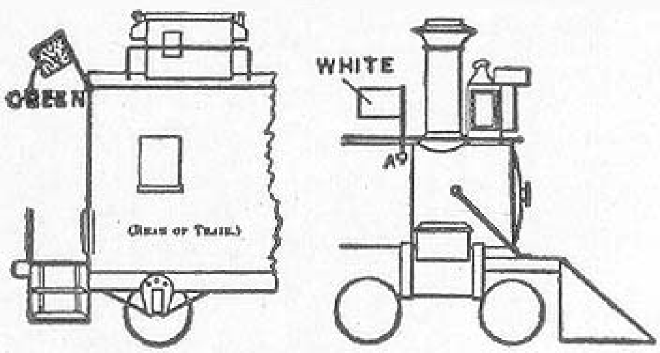

Fig. 109. Day Signal on Extra Train.

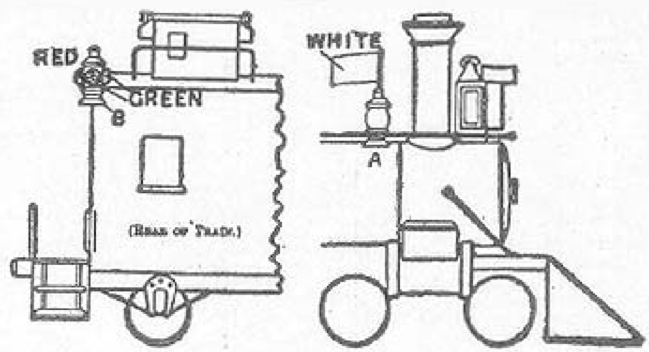

Fig. 110. Night Signal on Extra Train.

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

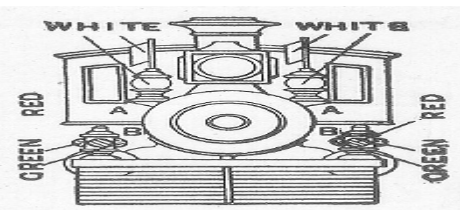

Fig. 111. Night Signal on Locomotive Running Backward, as an Extra.

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

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

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

Fig. 114 shows the arrangement of lights on the rear of the tender of a locomotive which is running backward by night. There is a single white light at *A*.

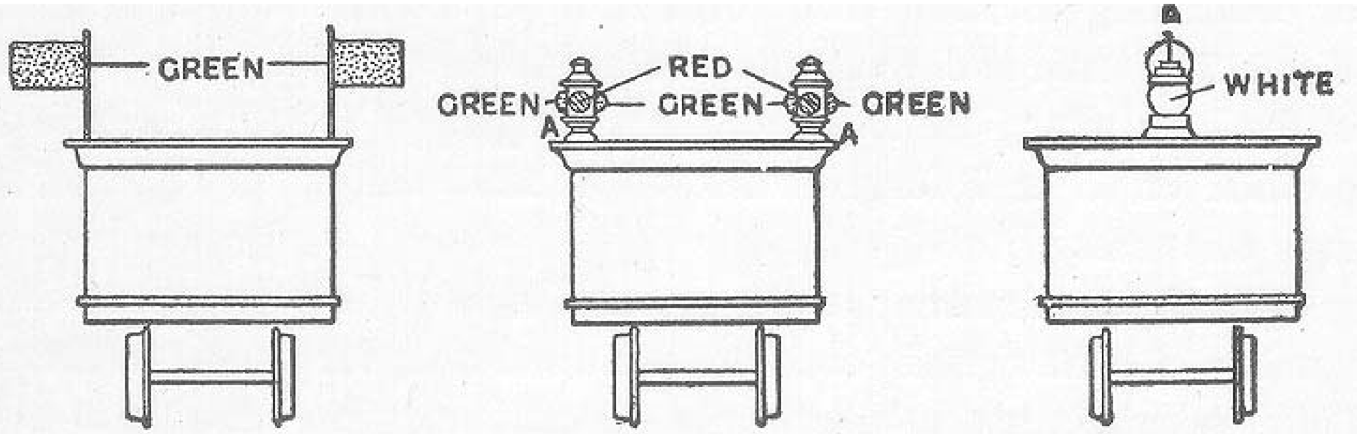

Fig. 112. Fig. 113. Fig. 114.
Signals on Tender for Engine Running Without Cars.

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

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

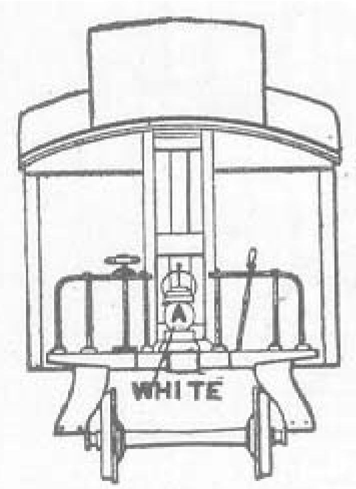

Fig. 115.
Night Signal for Passenger Train pushed by an Engine.

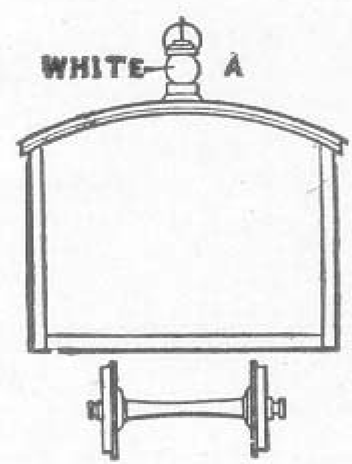

Fig. 116.
Night Signal for Freight Train Pushed by an Engine.

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

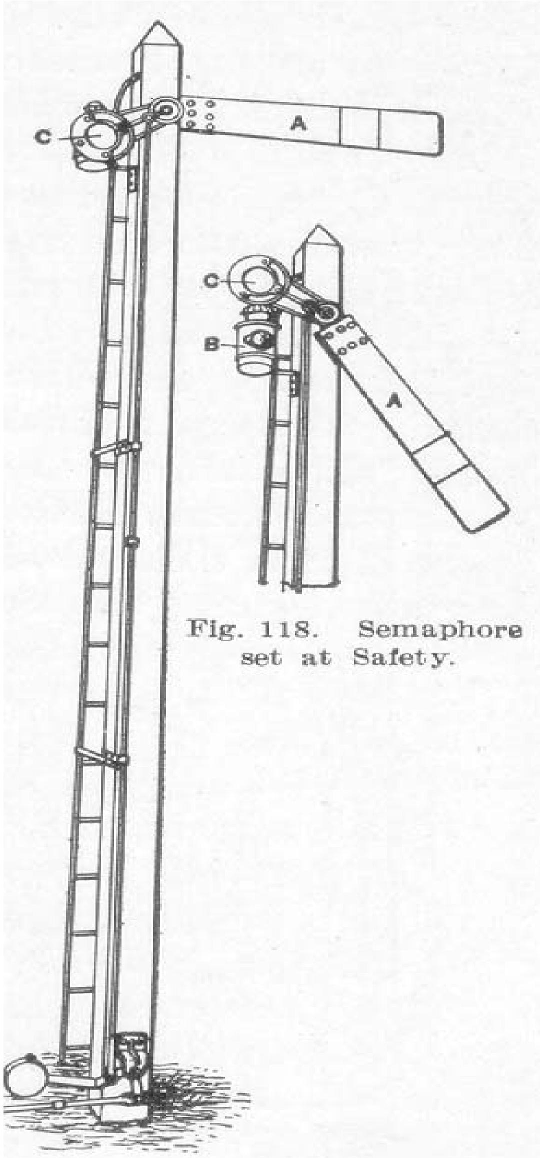

Fig. 118. Semaphore set at Safety.

Fig. 117. Semaphore Set at Danger Signal.

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

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

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

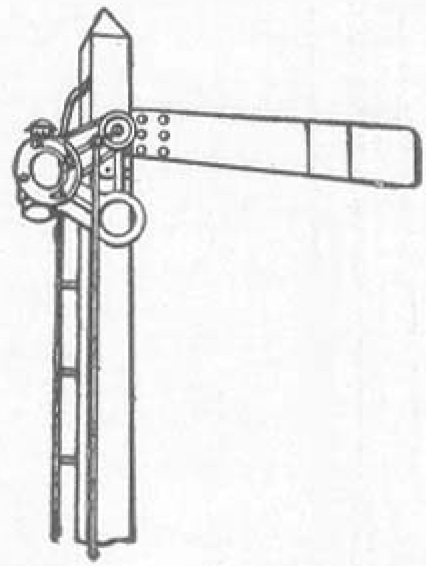

Fig. 119. Home Semaphore Signal.

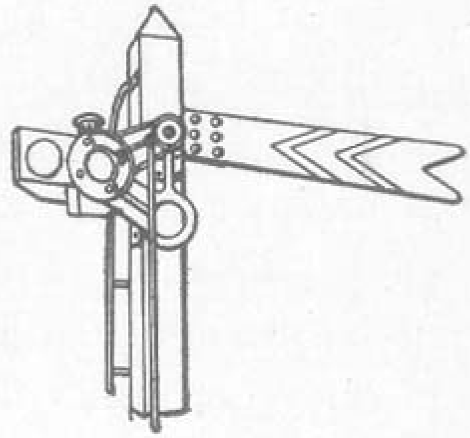

Fig. 120. Distance Semaphore Signal.

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

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

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

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

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

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

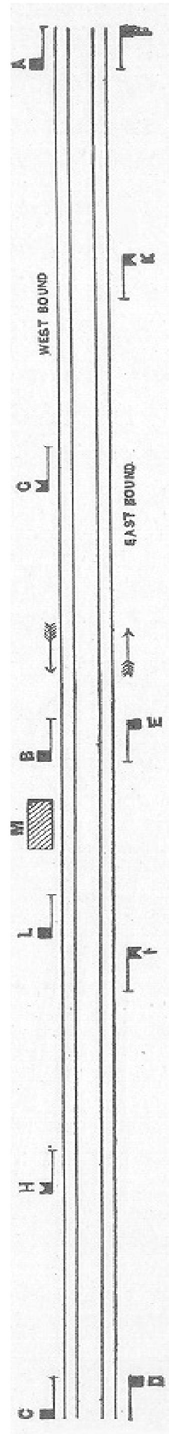

Fig. 121. Diagram of Lock and Block System.

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

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

1. *Each home signal, lever in that position which corresponds to the clear signal must lock the operating levers of all*

switches and switch locks which, by being moved during the passage of a train running according to that signal, might either throw it from the track, divert it from its intended course, or allow another train moving in either direction to come into collision with it.

2. *Each lever so locked must in one of its two positions lock the original home signal in its danger position, that position of the lever being taken which gives a position of switch or switch lock contrary to the route implied by the home signal when clear.*
3. *Each home signal should be so interlocked with the lever of its distance signal that it will be impossible to clear the distance signal until the home signal is clear.*
4. *Switch and lock levers should be so interlocked that crossings of continuous tracks cannot occur where such crossings are dependent upon the mutual position of switches.*
5. *Switch levers and other locking levers should be so interlocked that the lever operating a switch cannot be moved while that switch is locked.*

Levers at one signal station are locked from the station in advance. Thus, the signal *A*, Fig. 121, cannot be put to clear until freed by the operator at *B*. *B* cannot be cleared until freed by *C*, etc. Levers and signals may be operated by hand, pneumatic, or electric power, the last two either automatically or by an operator.

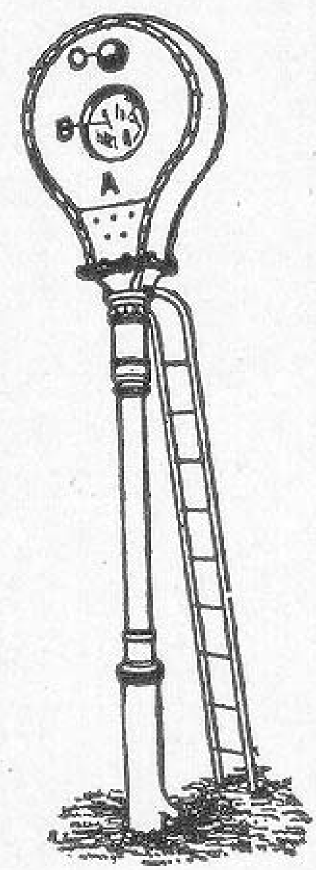

Fig. 122. Hall Disk Signal.

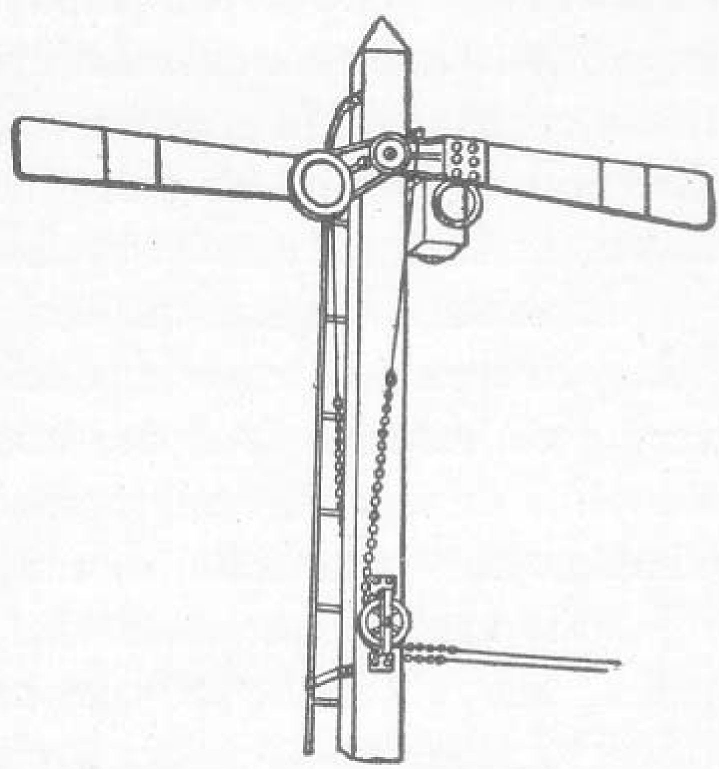

Fig. 123. Semaphore Block Signal for Single Track.

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

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

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

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

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

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

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

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

Different fuels require different treatment in the fire-box.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

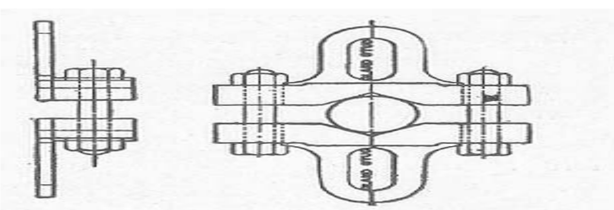

Fig. 124. Clamp for Repair of Broken Connecting Rod.

Broken Connecting Rod. If a connecting rod is broken without injury to the cylinder, the crosshead and piston should be blocked at one end of the stroke and the broken parts of the rod removed. The removal of the side rods depends upon the extent of injury to the crank pin on the broken side. All side rods should be left in position if the crank pin on the broken side is uninjured, otherwise all should be removed. The valve rod should be disconnected from the rocker arm and the valve stem clamped with the valve in the cental position. The valve stem may be clamped by screwing down one of the gland nuts more than the other, thus cramping the stem. It may also be secured by the use of the clamp shown in Fig. 124. This consists of two parts having V-shaped notches which are securely fastened to the valve stem by a bolt on either side. This is done after having passed the gland studs through the two slotted holes, which prevents any longitudinal movement of the stem after the nuts on the studs have been screwed home. The crosshead should be forced to one end of the guides with the piston against the cylinder head. In this position, it can be secured by a piece of wood cut to fit snugly between it and the guide yoke.

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

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

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

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

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

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

TRAIN RULES

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

All messages or orders respecting the movement of trains or the condition of track or bridges must be in writing. Passenger trains must not display signals for a following train without an order from the Superintendent, nor freight trains without an order from the Yard Master.

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

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

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

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

No train shall leave a station without a signal from its conductor. Conductors and engine men will be held equally responsible for the violation of any rules governing the safety of *their trains and they must take every precaution for the protection of their trains even if not provided for by the rules. In case of doubt or uncertainty, no risks should be taken.*

TIME TABLES

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

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

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

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

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

Trains are designated by numbers indicated on the time table.

LOCOMOTIVE TROUBLES AND REMEDIES
OPERATING PROBLEMS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

After washing the barrel completely, clean the back end of the arch flues, making sure they are free from scale. Next by using bent nozzles in the side and corner holes of the water legs, thoroughly clean the side sheets and finally clean off all scale and mud from the mud ring by means of straight nozzles in the corner holes. It should not be assumed that because the water runs clear from the boiler that it is clean and free from scale. Carefully examine all spaces with a rod and light and, if necessary, use a pick, steel scraper, or other suitable tool in removing the accumulation of scale.

Drifting. In operating a locomotive on the road the engine frequently runs with a closed throttle, as is the case in bringing the train to a stop or when "dropping" down grades. This condition is known and spoken of as *drifting*. Under such circumstances there may be little or no steam in the cylinders yet the effects of expansion and compression will be present. As a result, if the reverse lever is set near the central position the compression will be relatively high and expansion will be carried so far that a vacuum will result which will draw gases and cinders from the "front end" through the exhaust pipe into the cylinders. It is easily seen that the presence of smoke and cinders in the cylinders may prove to be a serious matter.

To prevent the conditions just described from arising, the reverse lever, when drifting, should be carried in the full position corresponding to the direction of travel, for in this position a vacuum will probably not be formed and no foreign matter will enter the cylinders. As a safeguard against damaged cylinders and valves both steam chests should be fitted with relief valves. Such valves are applied one to each steam chest and are arranged to open inwardly and admit atmospheric air whenever the pressure in the steam chest falls below that of the atmosphere and to close suddenly when the throttle is opened. They should be constructed to open by gravity so when once opened they will remain open and will not be worn out by being rapidly opened and closed during the drifting period. It is important that they be made of ample size to admit air freely, otherwise at high speeds a vacuum might be formed in the steam chests and smoke and cinders still be drawn into the cylinders.

Fuel Waste. Leaks or wastes of steam or hot "water are always a direct drain upon the coal pile from which no benefit is received. The different ways in which steam is wasted, which were considered under Steam Waste, constitute a loss of fuel. The presence of scale on the heating surface of the boiler reduces the amount of heat which could otherwise be transmitted, thus requiring more coal to be burned, which is a waste of fuel. There are other large wastes of fuel in which steam plays no part, such as the generation of smoke and carbon monoxide, the emission of sparks, and the loss of coal which never enters the fire door.

Waste from Smoke. Of all the losses attending the firing of bituminous coal that due to the generation of smoke attracts the most attention since it is so readily seen because of its color. When such coal is thrown into a hot furnace the lighter hydrocarbons are distilled off first, and if an insufficient supply of oxygen is furnished to completely burn them, smoke will be observed coming from the stack. The actual heat loss in carbon contained in the smoke is small as compared to that in the carbon monoxide gas formed. Both of these losses are due to an insufficient supply of oxygen furnished by the air. The presence of smoke indicates a shortage of air and for this reason is a valuable guide to efficient firing. The temperature must be maintained sufficiently high to burn the gases as they are driven off the coal. No part of the fire-box should be permitted to become chilled, and in order to maintain a uniform temperature over the entire surface of the fire, the coal must be evenly distributed. To insure rapid burning, the large pieces of coal should be broken up so as to present a more nearly uniform size. An alert and efficient fireman will endeavor to take advantage of the physical characteristics of the road and will fire lightly and regularly, keeping the fire door slightly open for a few seconds, if necessary, to admit sufficient air to burn the lighter gases which are driven off. The steam gage should be constantly watched and the supply of air regulated as far as possible by the dampers. Much good will result from the engineer co-operating with the fireman in handling the locomotive in an intelligent, manner and informing him from time to time of his intended movements.

Waste from Sparks. The loss in cinders and small pieces of coal being ejected through the stack is quite large. In extreme cases it may reach 10 or 15 per cent of the total weight of the coal fired. The heating value of these *sparks*, as they are usually termed, varies between 70 and 90 per cent of the coal as at first fired. Sparks are not only wasteful of coal but are very dangerous to property in the immediate vicinity of the track. For these reasons the fireman should endeavor at all times to handle his fire in such a manner as to minimize the amount of sparks formed, and the netting in the front end should be kept in constant repair to prevent large holes from forming which would permit large quantities of sparks to be thrown out.

LOCOMOTIVE BREAKDOWNS

Possible Causes. In the operation of a railroad it is of great importance that trains should be kept running on schedule as nearly as possible. It frequently happens, however, that accidents to the locomotive of greater or less consequence prevent trains from maintaining their schedules, which in many instances could be avoided by a little forethought on the part of the engineer. The efficient engineer who inspects his engine regularly for loose bolts, nuts, and keys, looks for defects, and carefully examines any cracks, flaws, etc., is seldom troubled with annoying and sometimes dangerous accidents while on the road. Breakdowns will, of course, occur at times even though all precautionary measures have been taken. Space will not permit of reference to the many different accidents which may occur. The following list contains those most commonly experienced:

1. Collision of two approaching trains
2. Collision of a moving with a standing train
3. Collision of trains at the crossing of two tracks
4. Running into an open drawbridge
5. Engine running with no one on it to bring it under control
6. Derailment of the front truck, drivers, or tender
7. Explosion of the boiler
8. Collapse of a flue
9. Overheated crown sheet
10. Running into an open switch at too great a speed
11. Blowing out of a bolt or cock or any accident which leaves a hole in the boiler for the escape of steam or water
12. Failure of the injectors or check valves
13. Breaking or bursting of a cylinder, cylinder head, steam chest, or steam pipe
14. Breaking or bending of a crank pin or connecting rod
15. Breaking of a tire, wheel, or axle
16. Breaking of a spring, spring hanger, or equalizer
17. Breaking of a frame
18. Failure of any part of the valve gear
19. Failure of the throttle valve
20. Breaking of the smoke-box front or door
21. Failure of the connection between the engine and tender or between the tender and first car
22. Failure of the air pump or braking apparatus

In case of an accident it is assumed that the engineer will first comply with his book of rules in regard to signals, flagman, etc., and will not overlook or neglect the boiler while working on a disabled engine. If the locomotive has left the track and is in such a position that the crown sheet is exposed, the fire should be killed at once if at all possible. This can be accomplished by throwing dirt, gravel, etc., into the fire-box. If water is convenient it can be used, but with great care.

Derailments. If the locomotive leaves the rails for any reason whatsoever, the throttle valve should be closed and the brakes applied. As soon as the locomotive has come to a stop, protection should be made against approaching or following trains. If the locomotive remains in an upright position and the crown sheet and flues are protected by being covered with water, the fire need not be drawn. In case they are exposed the fire should be drawn, or covered with dirt, gravel, or fine coal, or quenched with water. If not off too badly or too far away from the track, the engine can usually be made to help itself on without the aid of another by using blocking under the wheels and by the aid of "replacers". The engine can, as a rule, be placed on the track easier by moving it in a direction opposite to that in which it ran off.

If conditions are such that the locomotive cannot help itself on the track, it will probably be necessary to secure the assistance of another. If it is too great a distance from the track or over on its side, it will be necessary to send for the wrecking crew.

Explosion of Boiler. It is not always possible to determine the real cause of a boiler explosion, since it sometimes happens that all evidence is obliterated. It has been said that all boiler explosions are due to the fact "that the pressure inside the boiler is greater than the strength of the material of which the boiler is constructed". Failure is due to one of two causes, namely, insufficient strength to withstand the ordinary working pressures, or a gradual increase of pressure in excess of that which it was designed to carry.

Lack of strength may be due to incorrect design, defective material and workmanship, or reduction in size of plates, stays, etc., due to corrosion, wear and tear, and neglect. Overpressure is usually due to defective safety valves or to safety valves set by pressure gages which indicate pressures much less than the real amount.

Collapse of Flue. If a flue collapses while in service, the escaping steam and water will usually extinguish the fire. When the pressure is reduced sufficiently, an iron or wood plug can usually be driven into the ends of the tube in question, which will effect an emergency repair and permit the locomotive to return under its own steam. It may be necessary to run under a reduced steam pressure. The injectors should be used in reducing the pressure to make sure of plenty of water being kept in the boiler. Iron plugs are preferable but, if they are not at hand, wood plugs may be used. The iron plugs are placed with a long bar. The wood plugs are made on the end of a pole and partially cut off, so that when placed they can easily be broken off. The plug will burn slightly but not to any great extent inside the end of the flue. If the failure occurs in a flue located back of the steam pipes, it may be necessary to let the boiler cool down before the temporary repair can be made. If the steam obscures the back end of the flue, it sometimes can be drawn up the stack by starting the blower.

If a fitting is accidentally broken off permitting steam or water to blow out, or if a hole is made in any way which permits the escape of steam or water, either can be temporarily repaired in the manner indicated above. Metal plugs are preferable but wood can be used if necessary. In plugging flues or any holes where steam or water is escaping, care must be exercised to prevent being struck by the plug in case it blows out.

Disconnecting after Breakdown. The disconnecting of one side of a locomotive usually implies that the machine is to continue its journey. It is made necessary by an accident to a cylinder piston, piston rod, steam chest, valve gear, connecting rod, etc. As an example, let it be assumed that a locomotive has met with an accident and one of the cylinder castings is broken. The work that must be done in order that the locomotive may continue its journey is explained in the following:

Method of Procedure. If the crank-pin, connecting rod, and crosshead are uninjured, they need not be removed, but the piston rod should be disconnected from the crosshead and the piston and all removed from the cylinder. If, however, any of the above-mentioned parts are injured and will not function properly, then the main or connecting rod must be taken down on the injured side. In removing the rod care should be exercised to keep all the rod attachments in place as that will be of much assistance when replacing the rod. Next move the piston to the back end of the cylinder as far as it will go and fasten securely by placing wood blocks between the guides so as to fill the space between the cross-head and the end of the guide bars. As a safeguard the wood blocks should be secured by means of rope to prevent them from falling out of position should they become loosened. On some types of locomotives it may not be possible to block the piston in the extreme backward position because of a lack of clearance. In such cases the crosshead should be blocked in the forward position. The back position should be used whenever possible, because if the crosshead became loose in that position and was shot forward it would do less damage than if freed from the forward position. After the crosshead is securely blocked, the valve rod should be disconnected from the rocker and valve stem and the valve moved to its central position so as to cover both steam ports and prevent steam from entering the cylinder. By opening the cylinder cocks and slowly admitting steam by means of the throttle valve, it can be known whether or not the valve is correctly located. If not properly located steam will blow from one of the cylinder cocks. If no steam is discharged at either cylinder cock it is probably correctly set. When it has been correctly set the position of the valve must be secured by clamping the valve stem and wedging or tying it in place. With these changes properly made, the locomotive should be able to proceed on its way with but one side doing work.

In case of injury to both sides the locomotive would not be able to proceed under its own power. The connecting rods may be removed from both sides if the conditions demand it but the side rods should not be removed unless seriously damaged. When the locomotive is proceeding with one side only doing work and it is necessary to remove one or more of the side rods because of injury, the corresponding side rods on the other side should also be removed. Under such conditions the speed of the locomotive should be kept very low because of the effect of the counterbalance on the track.

When both sides are disconnected and the locomotive is being towed back to the shop, attention must be given to proper draining of the various pipes, etc., if the temperature is below the freezing point. It is never necessary to remove the eccentric straps unless it becomes so on account of some injury.

The accidents to a locomotive when in service are numerous. Some may be more serious than others. Space does not permit covering all the possible emergency repairs which it may be necessary to apply. In most cases the character of the breakdown will suggest the remedy.

DUTIES OF LOCOMOTIVE ENGINEER*

WATCHING HIS ROAD

* The following observations on Locomotive Driving were prepared by John H. Jallinga, Mechanical Engineer, Chicago.

Acquaintance with Route of Prime Importance. To the casual observer a locomotive runner has a fairly easy billet. Perhaps not one person in a hundred of those who see him sitting in his cab, complacently awaiting the signal to start his train, has any idea of the multiplicity of his duties.

Of course, as a prerequisite to all his other functions comes the care of his engine, either standing or under way, but interwoven with this knowledge are other matters of detail, for example, an intimate knowledge of his time table as it applies to the different parts of his-run. This he must have learned so thoroughly that he can instantly say how long it should take to travel on schedule time between any two points in his run. To be able to accomplish this it is absolutely essential that the engineer know the grades, the curves, the switches, the sidings, the crossings, the stations, and the semaphores he will have to go over or pass *en route*. This means that he will have to know them thoroughly, both backward and forward, for having completed his run today he will have to return by the same route tomorrow, in which case all these items will come to him in reverse order.

These features have such an important bearing on the successful performance of his duties that were he ever so skillful in the care of his engine, he would be quite incompetent to take his engine and train over another route which was unfamiliar to him. This statement may seem somewhat paradoxical, yet it is absolutely true and in our development we will try to make the reason clear.

Regulating Steam Supply. There is no type of boiler which has to supply such an abundance of steam on short notice as that of the locomotive. Nevertheless, with all its capabilities, conditions frequently arise during the run which test its capacity to the limit and make it absolutely necessary to conserve the boiler resources.

Preparing for Grade. Thus on approaching a heavy up-grade, the skillful engineer will see that his fireman so stokes his fire that there is a thick bed of fuel on the grates and will himself pump water into his boiler to as high a level as can be carried with safety; all this must be accomplished just before the engine arrives at the foot of the grade. While climbing the grade the feed water is shut off, the furnace door is kept closed, and the throttle opened just far enough to enable the engine to mount the grade on schedule time, making it without unnecessary strain or labor.

If these precautions are neglected, the fireman will have to shovel fuel so hard during the climb that he will become exhausted before the summit of the grade is reached; this drawback, coupled with the large losses in steaming capability due to opening the furnace door for the purpose of stoking, will prevent the engine from maintaining the requisite head of steam for making this part of the run on schedule time.

Good Firing Practice. Theoretically, no air should be permitted to enter the furnace that does not pass through the fire but in practice this cannot be accomplished, because every time the fire door is opened it admits a large volume of cold air which passes over (not through) the fire directly into the tubes, tending to cool the water and decreasing the boiler's steaming capacity, For this reason, the stoking should always be done a very few shovelsful at a time and the fire door quickly closed to give the fire a little time for recuperation before re-firing. Another very essential duty of the fireman in stoking is to watch for *holes* in the fire. For various reasons, some portions of the bed of fuel will burn out quicker than the rest, and wherever this occurs it leaves a hole through which air will pass in greater volume than through the rest of the fire; as this air is comparatively cooler than if it had forced its way through the burning fuel, it has the same effect on the steam-making power of the boiler as the open fire door, though not to the same extent. Hence, the skillful fireman, on opening his furnace door, will look for these holes and fill them with fuel when he fires; if more of them appear than he can fill at one time he must stoke more frequently.

The bed of fuel should be kept, as far as possible, at a uniform thickness of about 10 to 12 inches although some engines are designed for a heavier bed than this. The coal is usually broken into pieces of 2½ to 3 inches and enough for one stoking is laid on the deck of the engine before the fire door; the shovel is also heaped full and held ready before the fire door is opened, thus accomplishing the firing as quickly as possible.

Taking Advantage of Downgrade. It will readily be seen from the preceding description how essential it is that the driver and his fireman should know the exact location of the grades and the necessity for due preparation. Of course on the return trip the same grade will have to be retraversed but with all the running conditions reversed. In this case the throttle should be closed, the train running down hill without steam, and the reverse lever should be thrown forward into the last notch of the quadrant; this gives the cylinder valves full stroke in order to equalize the wear on the valve face as much as possible, for at this time the absence of any lubricant between the valve and cylinder face is liable to cause more rapid wear than under ordinary working conditions. Under such conditions in former days, it was a part of the fireman's duty to walk out on the foot board and tallow the valves, that is, to introduce a lubricant through a tallow cup in the steam chest cover. Today, most engines are fitted with sight-feed lubricators which feed cylinder oil constantly to the valves and cylinders while the engine is in motion under steam.

The attentive engineer will also take advantage of this opportunity to replenish the water in his boiler, if necessary, because he can pump up while not using steam and at the same time prevent the pressure in the boiler from rising to the blowing-off point. In the interests of economical operation, such a condition is to be avoided but may easily arise when no steam is being used and with fuel burning on the grate bars. For this reason the damper should be closed, care having been taken before reaching the downgrade to let the fuel bed get thin. On its way down, the fire can be cleaned and fresh fuel added in readiness to resume steam-making as soon as the level is reached again.

Curves. The exact location of every curve on the run must be known to acertainty, first, because it is essential, in order to avoid derailment and for general safety that the speed of the train be slackened below the normal while passing around curves. All curves are constructed with the outer rail some inches higher than the inner rail, the exact amount being determined by the radius of the curve and the speed with which the train should make the curve. This tilting of the train counteracts to some extent the centrifugal force developed in rounding the curve but this precaution must be supplemented by slackening the speed also. Again, many curves occur in cuts, that is, at places where it has been found essential, in making the roadbed, to cut through a small hill so as to preserve the uniformity of the grade. Sometimes a curve will occur in a woods or at the entrance to a forest, and it would be manifestly dangerous to approach and enter such a place without giving warning of the approach of the train. Hence it is the rule, when approaching a curve, to sound the whistle before arriving at the curve. This precaution is more especially essential if it be a single track road.

Switches. A knowledge and a clear remembrance of the location of all switches and sidings are necessary because of the liability of a switch onto the main line being left open through neglect or willfulness. Therefore, the driver on approaching a switch observes first of all the position of the switch target, next the position of the rails, never trusting to the target alone, for sometimes rods connecting the target with the track get disconnected or bent; the engineer can see very clearly whether the track he is running on forms one continuous line past the switch or not. He should, at the same time, assure himself that the frog and wing rails have not become misplaced. These are conditions that do not very often arise but when they do the consequences are so terrible, if not seen in time, that it pays to be on the lockout for them constantly. The main point is to have the train well in hand at all times, and to this end speed must be reduced when passing switches or the ends of sidings. All station yards have a number of switches, and it is customary to slow down while going through them, more especially if intending to stop there. But many trains pass through the smaller towns without stopping and must also frequently pass sidings at certain places on the line between stations and all these places must be watched closely by the driver. In order to do this properly, he must know beforehand when he is about to approach them.

Culverts and Bridges. The location of every culvert and every bridge must be known and a keen lockout kept for any derangement in connection with them. Swing and draw bridges are usually guarded by a semaphore, and it is the rule on nearly all roads that every train shall come to a FULL STOP about 200 feet from the bridge approach and await the dropping of the semaphore arm before proceeding, and then only at a slow speed until the bridge has been crossed.

Running Time. It is considered an unpardonable offense for an engine driver to arrive at a station ahead of time though some roads do allow one minute variation. This latter is not material, provided it is borne in mind and the rule lived up to; the idea is to have the right of way clear before the arrival of the train, for otherwise a very embarrassing result may ensue.

For these reasons it is very essential that the engine driver make himself thoroughly acquainted with his time table. He must not only know the exact time he is due at any station on his run, but he must know by rote just the number of miles between stations, mentally calculating the necessary speed of his train and seeing that his engine meets the requirements between stops. These speeds vary because of road conditions, and proper allowance must be made for grades, curves, conditions of roadbed, etc., otherwise it will be impossible for him to meet the requirements. Hence, the driver automatically registers in his mind certain landmarks along the road—a house here, a certain tree there, a hill, a stream, or a huge bowlder at other places—and he gets to know that he should pass each one of them at a given time going in one direction or the other. He also knows that a certain curve, a culvert, a siding, or a bridge lies one mile, a halfmile, or a quarter-mile beyond one or the other of his landmarks and by these indications he knows it is time for him to perform certain of the duties already described.

Block Signals. Many roads, especially in the older portions of this country where the traffic is heavy, use a double track extending for 80 or 90 miles outside some of the large cities and often all the way between important cities. Wherever double track is used, the block system of signals is installed, thus relieving the engine driver of many of the anxieties connected with running trains on a single track road and making the road safe for traffic.

It is not within the province of this article to discuss block signals except as to their effect on the duties of the man who watches over the destinies of the train committed to his care. Briefly, the right of way is divided into sections called blocks and at the commencement and end of every block there is a manually or automatically operated signal over each track; unless the driver sees that his signal shows the way is clear he must not enter a new block. On approaching a station, he must also look for the signals showing way clear and on arriving at a station must observe the semaphore arm projecting from the front of the station over the track; it may be that orders are awaiting him, which it is his duty to read and follow.

It will readily be seen from the above description of a portion of a locomotive driver's duties why it is essential to the proper performance of his work that he should know the road thoroughly.

Watching His Engine. While the engineer is attending to the matters just enumerated he must not neglect his engine. It would be a difficult matter to decide which of the numerous features to be watched are the most important but it goes without saying that the steam pressure and the water in the boiler are those which will require the most constant watching because they are liable to change, in fact are constantly changing unless foresight is used to keep them normal. In addition to these points, he must be eternally on the lockout for the condition of the working parts of the machine he is operating. To give a clear idea of the the conditions under which his machine is working, we will assume that he is running a passenger train and that his average speed between stations is 50 miles per hour and that the driving wheels are 5½ feet in diameter.

Oiling Parts. Now at a speed of 50 miles per hour the engine would have to make 260 revolutions per minute and all the reciprocating parts of the engine, such as the crossheads, the rock shaft, the pistons and rods, the valve stems and valves, the links and lifters, would vibrate just twice this number of times. This is very rapid motion for such heavy parts and there is a liability of great wear in these parts unless they are kept properly lubricated. The only time the engine man can get the opportunity of supplying them with oil is while his engine is standing, and usually the stops are short. Hence, he must see that these parts are provided with large oil cups holding a good supply of oil and feeding oil to the working parts of the machine in an exact and very regular manner. Lack of space will not permit a description here of the various devices in use, but whether the cups are made to feed through the medium of a spring, of reciprocating parts, or of capilliary attraction, the engineer must be thoroughly familiar with their operation; in his leisure time in the roundhouse he should see to it that the oiling devices are so adjusted that they will perform their required functions while the engine is on the road. Some of the moving parts require more oil than others and the feed of the various oil cups must be set to suit the requirements; if any cup should feed too fast, it will waste the lubricant and probably will run out of oil too soon, or if too slow the moving part will run dry and cut.

All engines are provided with two oils, one of a heavy body for such places as the pedestal boxes in which the axles of the driving wheels run and on the journals of which there is an enormous pressure, and the other a light oil for the connecting rods, guides, links, lifters, eccentrics, rock and tumbling shafts. The pedestal boxes have a large reservoir called a *cellar* and a means of keeping the oil always against the lower part of the journal and hence these parts do not require such constant watching. The other parts mentioned, however, have to be watched constantly and the amount of watchfulness required is not always the same for the different parts at all times, for weather conditions frequently influence them. For instance, certain parts—such as the eccentric straps, the guides, the links, and lifters—in ordinary weather or on damp cool days will run very smooth and cool while on a hot dry dusty day they will need careful watching; the dust raised from the roadbed by the rapid motion of the engine over it will be quite considerable and a large amount of it will settle on these parts in the form of grit which will cut the parts badly unless the oil feed is liberal and frequently replenished. For all these reasons, the careful man will, when his train stops at a station for a minute or two, jump down from his cab with his oil can and walk round his engine, touching the ends of the driving axles, the crank pins, etc., with the back of his left hand to ascertain if their temperature is normal and at the same time replenishing the oil cups if found necessary. He does not oil every part in this way each time but divides them up mentally into groups, oiling one group at one stopping place and another at some future time; nor does he go through the oiling process at every station unless these are quite far apart. Experience teaches him about how often to do it, a good maxim being to oil too often rather than sparingly until he has learned just how much is needed and how often. The back of the hand is used to try the temperature of the bearing because it is considered more sensitive than the palm or the ends of the fingers owing to the absence of calloused skin.

Very few engineers travel without a supply of flour of sulphur to use in case of a hot box.

On the Road. *Starting*. On starting out from a station the reverse lever is thrown forward into or nearly to the last notch in the quadrant. The cylinder cocks are opened and, when the signal comes to start, steam is admitted to the cylinders and the engine starts slowly. After running a short distance so that the train has acquired some momentum and the cylinders have become warmed, the cylinder cocks are closed and the reverse lever is pulled up several notches on the quadrant. This has the effect of making the travel of the valve shorter, of giving more lead to the valve, and of cutting off the supply of steam to each end of the cylinders before the end of the stroke; at the same time the throttle is opened a little wider. The effect of all this is to cause the steam to impinge on the pistons at the beginning of each stroke with more force and in greater volume, with the result that the engine picks up, or increases its speed; when this condition has been attained, the reverse lever is pulled up a few more notches and the throttle opened a little wider until the desired speed has been attained.

Running at Speed. Now while this is being done the engine man does not for one moment take his eyes off the right of way; he is watching the track, the semaphores, and everything before him. Having gotten safely away from the station yard and out on the main track, he then has time to look at the pressure and water gages, etc., a glance being sufficient to show him if everything is as it should be. He may seat himself or he may stand on the foot board, as suits his convenience, but the careful man will, in either position, keep his hand almost constantly on the reverse lever; this is his means of knowing if his *motion* is working right. By this term is meant that part of the mechanism which operates the cylinder or distributing valves, such as the eccentric rods, the links, the lifters, etc. Should anything happen to any of these parts it can be instantly detected if his hand is on the reverse lever. In addition to this, the engineer's attention is directed to the main and side rods on his side of the engine and to the beat of the exhaust steam as it escapes from the smokestack. An experienced engine man, listening to the exhaust of his own engine or of an engine at a distance, can tell at once whether the valves are working square. He can discern at once by the pulsations of the engine he is riding on, if all the parts are working in unison.

The attentive and careful man never allows his mind to wander for a moment from these symptoms for it is imperative, in case of emergency, that he act quickly. To this end he devotes a portion of his leisure time to thinking up what will be the best course of action in certain emergencies, going over carefully every possible occurrence that might take place and what should best be done under the circumstances. These matters he commits carefully to memory so that when the emergency arises he will act instantly without reflection, for when the time arrives to act there is no time to reflect or consider, and unless he is prepared beforehand he will be lost. Consequently, whenever a fellow craftsman meets with a casualty he is interested to learn all the details, including the course of action taken under the circumstances and the criticisms of those who are experienced in such matters. This gradually educates his mind to such a point that when anything happens to his engine he acts automatically much more quickly than anyone can think.

Making Adjustments En Route. The pedestal boxes, brasses on the connecting rods, eccentric straps, and other moving parts are usually adjusted by the engineer while *en route* because these matters cannot be attended to in the shop. A knocking connecting or side rod must be tightened up a very little at a time until the knock is all taken out; if tightened up all at once it would heat, so it is adjusted a little at a time until it runs quietly. The side, or parallel, rods can never be made to run as closely keyed up as the connecting rods because they do not need to be and because a certain amount of looseness is desirable. These rods are always fitted with about 1/16-inch side play between the collars on the pins because in rounding a curve, the driving and trailing wheels are not exactly in line and if the brass boxes in these rods fitted snug between the collars on the pins they would jam and become sprung. Hence, when the engine is standing and he sees that on one side of the engine the pins of these wheels are in a horizontal position, he takes hold of the rod in the middle and tries it to see if it will move freely sidewise.

The proper length of a side rod, between center and center of boxes, should be identical with the distance between center and center of the axles of these wheels and if a little adjustment is required for the pedestal boxes, the centers of both rod and axles should be *trammed* to see if they agree. But this is a job for the shop man.

Any other derangements noticed by the engineer are reported by him to the shop foreman for attention by his staff.

End of Run. At the termination of his run the engineer should come into his last station with a thin fire on his grates and just enough steam to make the roundhouse. Whether he leaves his engine at this point depends on the relative locations of the depot and roundhouse. In some localities the engineer must take his train into the yards and shunt it into a siding before he leaves it; in others his engine is taken charge of by a man from the roundhouse, called a *hostler*, who takes the engine direct to the roundhouse while a switching engine does the shunting of the train.

When, however, the engineer returns to take out his train again he carefully looks the engine over to see that everything is in adjustment—all oil cups filled and working, fire in good shape, steam and air pressures right, and the hose couplings properly connected. He should also look into his sand box (this should really be done in the roundhouse) to see that his supply of sand is sufficient and dry enough to run out if required. When he has tried his air to see if the brakes are working, he is ready for another start.