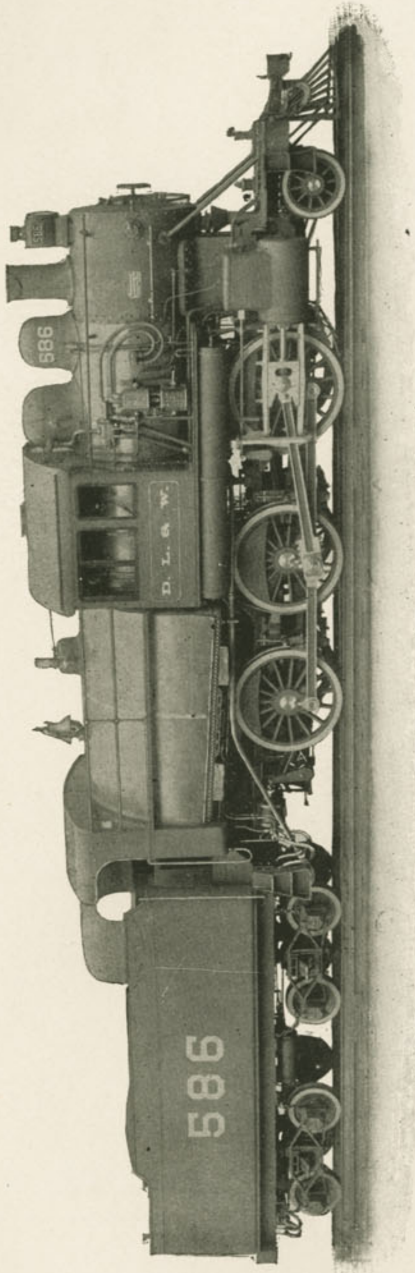
ICAL

DING

I

L OF
IVES.
DS,
ARS,
ART,
ORS.



MOGUL TYPE LOCOMOTIVE USED ON THE DELAWARE, LACKAWANNA & WESTERN R. R.
(American Locomotive Company)

PRACTICAL RAILROADING

A NEW, COMPLETE AND PRACTICAL TREATISE ON STEAM, ELECTRIC AND MOTOR CAR OPERATION

INCLUDING

A DESCRIPTION OF ALL THE VARIOUS PARTS OF THE DIFFERENT TYPES OF LOCOMOTIVES, THEIR PRINCIPLES OF OPERATION, MANAGEMENT, REPAIR AND MAINTENANCE; ALSO THE AIR BRAKE, MECHANICAL STOKERS, FEED WATER HEATERS, SUPERHEATERS, AND THE LATEST DEVELOPMENTS IN THE RAILWAY FIELD

WRITTEN EXPRESSLY FOR THE

MASTER MECHANIC, TRAVELING ENGINEER
LOCOMOTIVE ENGINEER AND FIREMAN

OSCAR C. SCHMIDT
Consulting Editor

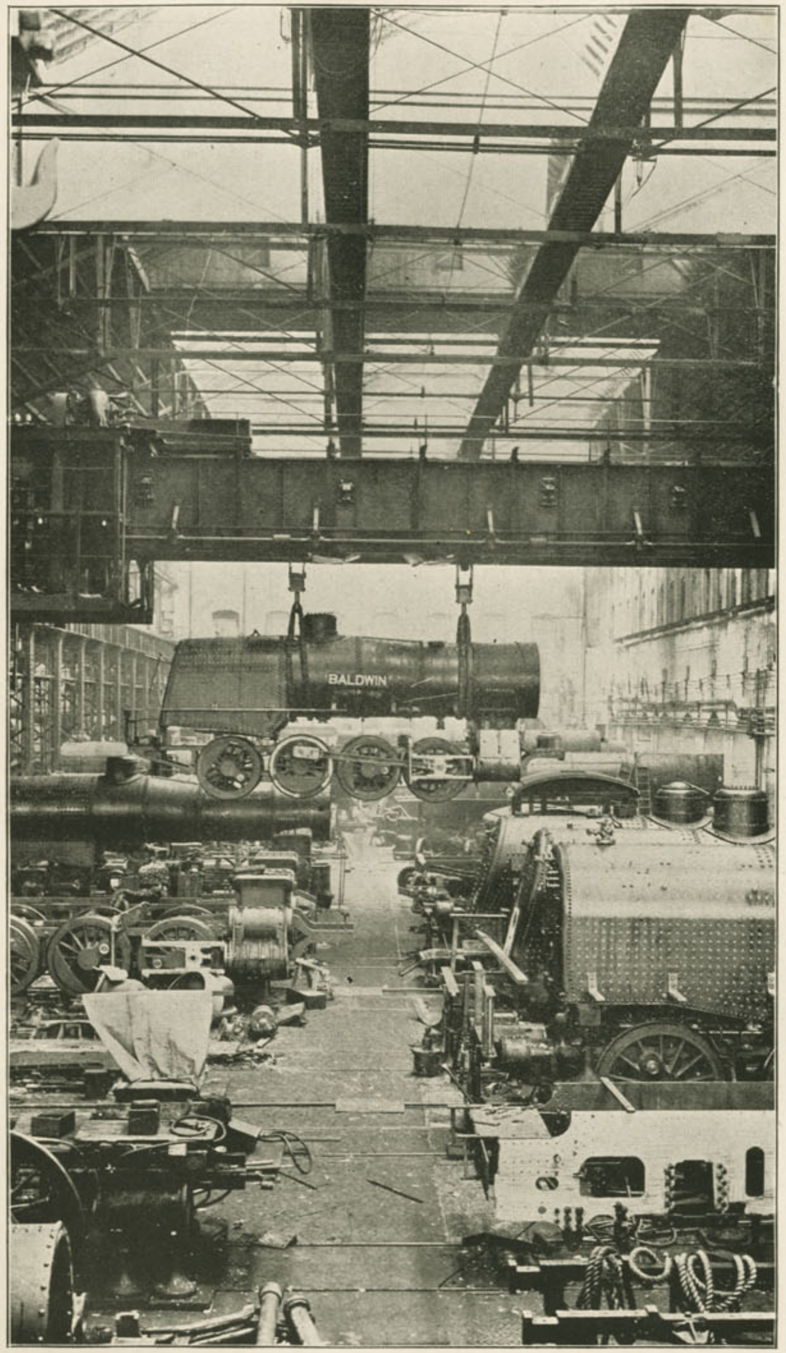
PROFUSELY ILLUSTRATED WITH HALF-TONES, DIAGRAMS AND LINE CUTS

1913 EDITION

STANLEY INSTITUTE
PHILADELPHIA

VOLUME II.

PAGE



LOCOMOTIVE SUSPENDED ON 100-TON TRAVELING CRANE IN ERECTING SHOP
(Baldwin Locomotive Works)

Construction and Design of Boilers.

A complete discussion of the general subject of "Strength of Materials" cannot be taken up here, but some of the more important branches entering into the construction of boilers will be touched upon briefly. The breakdown or failure of certain mechanical devices is attended with no greater disaster than their own loss, or perhaps the throwing out of use for a time certain other machines, of which the one in question is one link in the chain; but when anything happens to the boiler it is not unlike a failure of the heart to send the blood coursing through the body. And it is not merely the loss of energy: far worse is the disaster in most cases, ofttimes coming with little or no warning and causing dire calamity. The energy of steam and hot water is so largely latent, and so ready is steam to expand, that when one small flaw yields to the pressure, the tremendous following-up power of the expanding steam sends the ruptured parts of an exploded boiler long distances, causing great damage to life and property, not merely in the immediate vicinity of the boiler, but at considerable distances as well.

A careful study should, therefore, be made of the properties of materials and the methods of calculating stresses before undertaking the construction of a boiler. It should not be left there, however, for a boiler properly designed will not remain safe indefinitely without considerable attention, and in many cases constant repairs; this is particularly true where feed water is of poor quality, either through solid matter or chemical compounds, which cause scale and deposits within the boiler, either on the tubes or on the shell, or both. While the evaporative efficiency is largely reduced, the still worse trouble is met, that particularly in the case of the shell, or at a joint, the material may be overheated, the water within not carrying off the heat, and then rupture coming unexpectedly. If the safety valve should fail to lift, the fireman would be expected to note the rise in pressure by the steam gage and meet the difficulty in time; but a trouble coming from such a source as scale and mud might cause a serious explosion with no more than normal pressure.

Many States have laws covering the inspection and licensing of steam boilers, but most users of plants carry boiler insurance in some standard company, whose guarantee means that all details are properly carried out. The reputable boiler makers work in harmony with these companies, so that where even average good care is given by the attendants we have but comparatively few losses from boiler explosions.

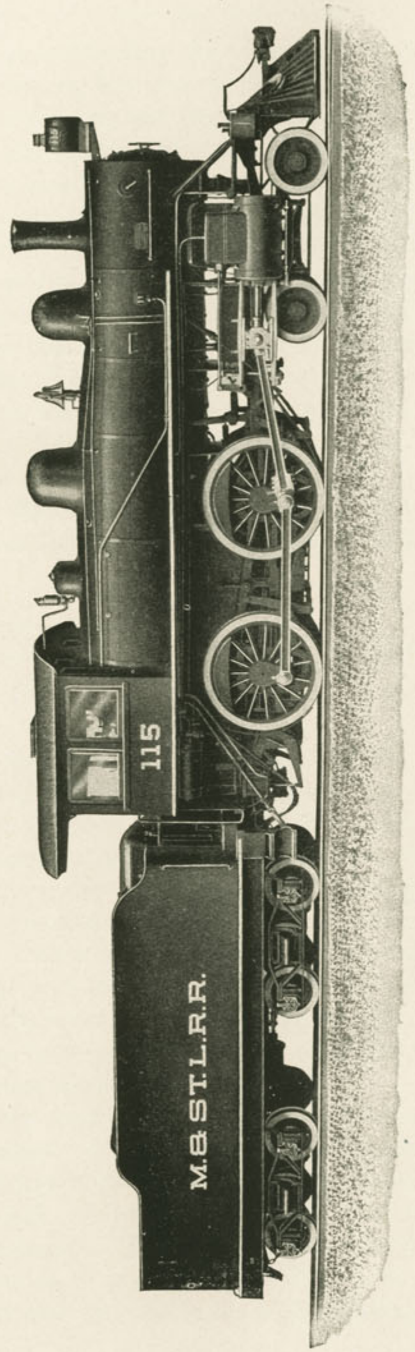
Materials. Wrought iron, malleable iron, cast iron, mild steel, copper, and compositions such as bronze and brass, enter into boiler construction. Nickel steel has been suggested, but its use has been very small. Of these materials wrought iron and mild steel are the most generally used for shells; the compositions and copper for flues, tubes, furnaces, etc., while cast and malleable iron furnish manhole and handhole rings, plates and yokes, brackets, steam outlets, etc. These various materials should be tested for

1. Tensile strength, or resistance to direct pull along axis of piece.
2. Compressive strength, or resistance to direct thrust along axis of piece.
3. Transverse strength, or resistance to bending.
4. Shearing strength.
5. Torsional strength.

Not only are the figures representing ultimate or breaking strengths of interest and value, but also the elastic limit and reduction of area should be given.

By elastic limit is meant in general that point to which a piece may be strained, and upon removal of the load have the piece return to its original dimensions. It has been found that up to a certain point Hooke's Law holds; that is, "*The stress is proportional to the strain.*" The stress is the amount of the force acting, and the strain is the distortion of the piece.

The *Modulus of Elasticity*, so called, is the stress, usually expressed in pounds per square inch, divided by the strain per unit length expressed in inches or fractions. If a piece is strained beyond its elastic limit it acquires a permanent set, hence the



EIGHT WHEEL TYPE PASSENGER LOCOMOTIVE
(American Locomotive Company)

importance of proportioning the several parts so that not merely the working pressure, but also the test pressure, which in the case of boilers is usually one and one-half times the working pressure, may not cause any permanent change in the size of the parts. Unfortunately, the elastic limit is not a perfectly definite point, but may vary in portions of the same material, depending upon the previous treatment, that is, whether cooled from a red heat quickly or slowly, hammered, rolled, etc. It may go from about 40 to 45 per cent of the tensile strength to nearly the full amount. However, it may be determined for a particular specimen with some certainty, so that if the specimen has been cut from the particular plate in question we have figures upon which we may depend with some security. The question of homogeneity of the plate, of course, must be considered.

Shapes of Specimens. In the case of rods or bars, the test pieces should be about two feet long, and surely not less than 18

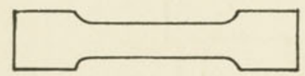


Fig. 1

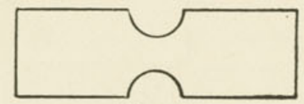


Fig. 2

inches. The data will be much more reliable if obtained from full-sized pieces, although they can, in the case of large pieces, be turned or planed down. Specimens from the plates should be taken from every lot, and some specifications require every plate to be tested. As the rolling tends to develop a grain in either iron or steel plate, pieces should be tested both along the grain and at right angles. Unless the material be very hard, the jaws of the testing machine will grip the ends of the test piece easily, or the specimen may be shouldered thus (Fig. 1):
but the distance between the shoulders should be ten inches at least. Necked specimens such as this (Fig. 2):
show a relatively greater strength per square inch of section than straight specimens. Undoubtedly, the metal across the neck does not flow as readily under stress, being supported somewhat by the adjacent material. Advantage may be taken of this fact under certain circumstances. If the metal is too hard to be gripped by the testing machine, it is probably too hard to be used, for it will be low in ductility and unsuitable for boiler making.

Cast metal usually gives much higher breaking strengths when tested without cutting the skin formed by casting. Samples should be not less than one inch by one and one-half inches. In certain cases it may be necessary to shape up a test specimen, but allowance ought to be made. In general, the testing should duplicate, as far as possible, the actual working condition. If, therefore, the casting is used as it comes from the sand, let the test piece be treated similarly, or, if the casting is to be planed before using, test a planed sample.

Testing. The testing machine is provided with two heads, one of which (P, Fig. 3) transmits the pull to the test piece, and the other carries the pull to the train of levers where the pull is weighed. The straining force is often applied through a train

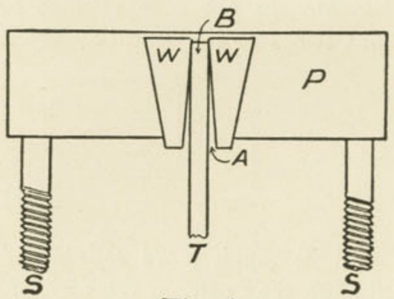


Fig. 3

of gears to bevel gears and lead screws S S, actuated by a crank and driven by hand or by power. An hydraulic cylinder may be used, drawing the fluid, as, for example, oil, from a reservoir under pressure supplied by a pump, or directly from the pump itself. This latter form, using a multiple cylinder pump with a device to regulate the amount of oil pumped, is quite successful.

The weighing is accomplished by means of a train of levers and a graduated arm, upon which the counterbalancing weight may be moved as the load is changed. The ends of the test piece are gripped by wedges having a very slight taper, so that the greater the pull the greater the grip. This, of course, applies to tension. These wedges W, W taper slightly on the other side, and a less amount than where gripped by the head; the surfaces which grip the specimens are scored, and the whole adjustment is such

that the grip is least at the lower point A and greatest at the outer point B. T is the test piece.

For compression, flat, parallel bearing surfaces are put in the heads. Small specimens may be tested transversely in such a machine, but the necessary auxiliary apparatus is bothersome to handle, and it is more satisfactory to use a machine constructed for that purpose. Such a machine is essentially (Fig. 4) a heavy girder G, carrying two jack screws acting at J, J, on which rests

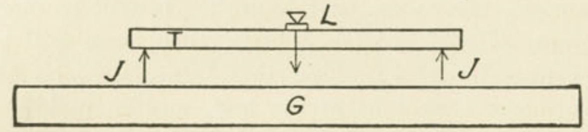


Fig. 4

the test piece T; a yoke L connects with the weighing beam, which is like a regular platform scale beam, through a train of levers.

If a distributed load is desired, the number of bearing points may be increased, and by knife edges and short girders as close an approximation obtained as may be desired. In Fig. 5 eight knife edges are equally spaced on the beam G to be tested; each pair carries a short girder and this girder has a knife edge at its center, and so on until a long girder H connects the upper pair

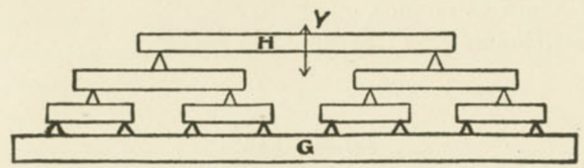


Fig. 5

of knife edges, and through the yoke Y transmits the pull to the scale beam.

In testing under tension a good method is to put two collars on the specimen, clamping them rigidly about eight inches apart. The two surfaces of the collars facing each other should have two or more raised points opposite each other, so as to allow the distance between one point and its fellow in the other collar to be measured by means of an extension micrometer caliper. This measuring should be accurate to one or two ten-thousandths of an inch. There is liable to be some little irregularity with the stretch measurements when the load is first put on, owing to lack of alignment, or if the piece is not straight. The load should be applied in uniform increments, and the measurements of the distances between the pairs of points on the collars taken. The average of the measurements for the several pairs of points should be taken as the length under that load. With each increment of load should come the corresponding increase in length, but when the stretch is greater for a given increment of load than for the preceding equal increment, this is the stretch limit. It will be seen that if the increments of load are taken large, then there will be a corresponding uncertainty in fixing this limit. But, on the other hand, the process is tedious at the best, and in making a large number of measurements much time and energy are consumed. An automatic device is sometimes used to register loads and corresponding stretches, but it should be noted that such a device ordinarily registers stretch limit and not elastic limit.

The Stretch Limit is sometimes defined as the point at which the specimen will not hold its load, but will allow the scale beam to fall when the straining motion is stopped.

Let A=area of cross-section of test piece in square inches,
l=length measured in inches,
P=pull in pounds,
e=elongation of section l in inches.

$$\text{Stress}=p=\frac{P}{A}$$

$$\text{Strain}=\alpha=\frac{e}{l}$$

$$\text{Modulus of Elasticity}=\frac{p}{\alpha}=\frac{Pl}{Ae}=E$$

If we take *f*, the working strength of mild steel, as 9,000 pounds per square inch (factor of safety=6), then we would have

$$P=fA \text{ and}$$

$$\alpha=\frac{f}{E}$$

$$\therefore \alpha=\frac{P}{EA}$$

$$\alpha=\frac{9000}{30000000}=\frac{3}{10000}$$

A bar 10 feet long could, therefore, be stretched $\frac{3}{10000}\times 10$ $=\frac{3}{1000}$ of a foot safely, and it would return to its original dimension very nearly upon removing the load.

Ultimate Strength. After passing the elastic limit in testing, it is of no practical advantage to take stretch measurements; it is customary to apply the load continuously until rupture takes place. The maximum load borne by a specimen is taken as its ultimate strength. If the load is applied rapidly this figure is likely to be higher than if the application be slower. It is to be hoped that engineers agree on some standard method of procedure, in order to assure universal comparisons to be made intelligently.

Ultimate Elongation. If the two pieces be laid together after rupture, with ends touching, the increase in length (between the marked points) divided by the original length gives the ratio of ultimate elongation.

Contraction of Area. The contraction or reduction of area of a specimen is to be carefully noted. The final area of the broken section is very much less in material of high ductility than was the original section. Oblique strains are sure to come in a boiler, and it is of importance to have the parts adjust themselves to such conditions as readily as possible. Too hard and unyielding material is likely to let go, or at least start a crack. A common specification for boiler plate is to have a piece whose length is 18 or 20 times the thickness of the plate, bent upon itself and hammered down close, all done cold, without showing fracture; this applies to plate ½ inch or under. Above this thickness it should be bent over a rod of diameter one and one-half times the thickness of the plate.

Shearing is that stress which tends to slide one section by the other, as in a riveted joint. With uniform bearing, as of the plate

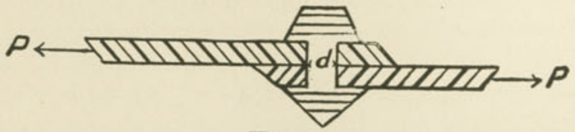


Fig. 6

on the rivet, the rivet heads being drawn up close to the plate, the resistance to shearing will be in the area of the cross-section of the rivet.

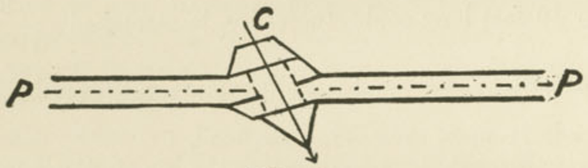


Fig. 7

P=pull on one rivet,
d=diameter shank of rivet,
f_s=shearing strength of rivet,
$P=\frac{1}{4}\,\pi\,d^2\,f_s$.

A suitable factor of safety must, of course, be used in figuring working loads. In the above sketch (Fig. 6) the pull coming along the plate, one end overlapping the other, makes the pull on the rivet more or less oblique, and tends to bend the joint somewhat, as in Fig. 7, when the center lines of the plates tend to come into the same line; in such a case, or where there is a definite oblique pull, the stress on the rivet is partly tension and partly shearing. The forces may be resolved by the parallelogram method as follows, Fig. 7a:

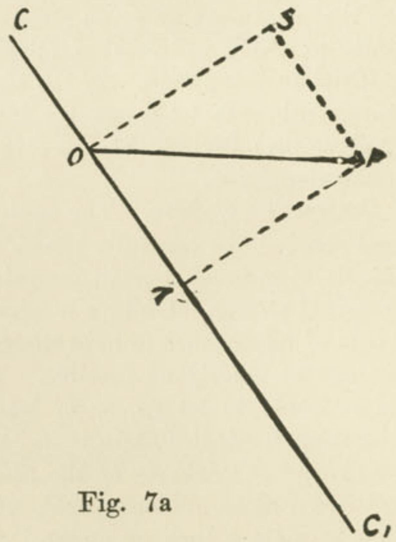


Fig. 7a

Let O P represent the stress with relation to C C_1, the center line of the rivet. The length of O P represents the amount of the force to scale. Draw P T at right-angles to C C_1 through P and complete the parallelogram. Then O S represents the shearing force and O T the direct pull. Neither should be allowed to exceed the safe load for the condition.

Eccentric Loads. In any structure, however carefully designed, we are likely to have eccentric loads. In tension members, as in the case just cited, the tendency is to pull the parts into line and rectify the eccentricity. But this may cause an overstraining of some part. For example, a hook, Fig. 8, may be overhung to get around some obstruction, and obviously will fail before it can take the load by direct pull through the stock above the hook proper.

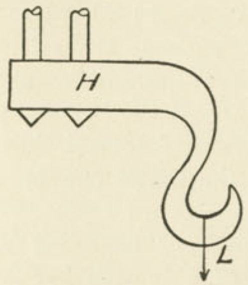


Fig. 8

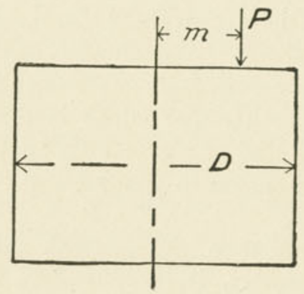


Fig. 8a

The horizontal part H is not only strained by the direct pull at L, but is also strained by a transverse load acting as a cantilever. Eccentric loading may and often does occur in compression members, as, for instance, short struts and columns.

In Fig. 8a let P be an eccentric load, A be area of cross-section, m be eccentricity of P. Then there will be a stress of $\frac{P}{A}$ per unit area due to the direct load, and from its action like a beam another stress of

$$P \times m \times \frac{D}{2} \div I$$

where I is the moment of inertia of the section and D is the diameter. That is, the maximum compression will be

$$\frac{P}{A} + P \times m \times \frac{D}{2} \div I$$

Eccentric loads are more likely to occur, and sometimes unexpectedly, in compression than in tension members, so that all care should be taken in the design in the first instance to have the loads central, and in the inspection and up-keep in the second instance to preserve alignments. The stresses coming from lack or change of alignment may be excessive and the cause of disaster. In other words, the part that is strong enough in its intended position may ultimately fail through overloading due to a slight derangement.

Repeated Stress. This subject may be discussed at great length, but it will suffice to say here that a part which is to bear a constant and unchanging stress is in a much better condition than one in which the stress recurs and releases alternately. Such a part should be more ample in size and subject to careful inspection. Distinction should be made between a dead load, a live load, and a shock. A gradually applied load, such as the raising of steam pressure from cold water in a boiler, is quite different from the water hammer which is often encountered in a steam plant. Many a line of pipe strong enough to withstand several times the working pressure has been wrecked by the shock due to water hammer.

Resilience. In general, this term means "bounding back." Mechanically, it is defined in the case of a tension bar as the mechanical work performed in elongating the bar the amount it would stretch under the greatest allowable load, applied gradually and without shock. In amount the resilience would be the product of the greatest allowable load into one-half the corresponding elongation. Again, it might be called the work necessary to overcome the resistance up to the limit of elasticity.

BOILER MATERIALS.

Wrought Iron. Although formerly a large amount of wrought iron was used for all parts of boilers, to-day mild steel is the material for shells, heads, etc. Wrought iron is liable to a lack of uniformity and homogeneity, which makes it rather undesirable in such a form as a large plate; but it welds so readily that a joint may be stronger than the original section. In fact, wrought iron cut up into billets, piled, heated, and forged, improves in a marked degree. Stays, braces, and fastenings, where welding is necessary, are best made of wrought iron.

Wrought iron in general will stand more abuse than steel in working; it may be worked at any temperature, even at blue heat, and will bend double cold without showing flaw. But wrought iron of this character is more difficult to obtain than mild steel, and is more expensive. In plates the tensile strength should be about 44,000 to 45,000 pounds per square inch, the elastic limit being about half this amount. In rods and bolts the strength may be taken somewhat higher, about 48,000 to 50,000 pounds per square inch. The shearing strength of rivets may be taken as 38,000 pounds per square inch. The weight of one cubic foot of wrought iron is not far from 480 pounds.

Cast Iron. On account of the great facility with which this form of iron may be melted and poured, special forms where flanges, lugs, etc., are desired may be made quite easily. It is much below wrought iron in tensile strength, but in compression is stronger, going as high as 80,000 pounds per square inch. As a hard skin forms on the outside of a casting, and this is greater in proportion to the area of the section in small pieces than in large ones, it may help to account for the fact that the strength of large pieces may fall off to 30,000 pounds per square inch. Where possible, this skin should not be removed.

According to the shape of the piece the tensile strength may range from 12,000 to 20,000 pounds per square inch. Gun iron made with the greatest care from the best stock may go as high as 30,000 pounds per square inch in tension. Used for elbows and joints in piping, cast iron is useful, for when changes are desired such a joint may be cracked open by a few sharp blows. Hand-hole and manhole plates and rings are sometimes cast, as well as nozzles, but owing to the brittleness of cast iron are unreliable. Changes in temperature are likely to cause stresses from unequal expansion. Cast iron weighs from 430 to 450 pounds per cubic foot.

Malleable Iron. Cast iron carries a considerable amount of free carbon. By removing some of it the casting is toughened, bringing it to a state somewhat like wrought iron. It will stand hammering to some extent cold, but the gain is not enough to allow any particular advantage in the matter of weight.

Steel. Mild steel made by the open hearth process, is largely used now for boiler making. It is tough, homogeneous, and ductile. In reality it is an ingot iron, the carbon running from $\frac{1}{10}$ to $\frac{1}{4}$ of one per cent, manganese less than $\frac{1}{2}$ per cent, with phosphorous and sulphur each less than $\frac{1}{25}$ per cent; some silicon may be found. Phosphorus makes the material cold short, and sulphur, hot short, both of which are undesirable qualities. Steel boiler plate, which is found to harden appreciably after heating and cooling, is to be viewed with suspicion in proportion to the amount of the hardening; such plates should not be used. As the ingot is cast, the upper or crop end is likely to be more or less imperfect and to contain bubbles of gas. When rolled out, laminations are likely to occur, so that this crop end of the ingot should be cut off before rolling is commenced, and cut long enough to take in all the bubbles and imperfections.

Mild steel boiler plate may be counted on as having a tensile strength of 55,000 to 65,000 pounds per square inch, with an elastic limit of 30,000 to 33,000 pounds per square inch; reduction of area of broken section not less than 50 per cent, and for an 8-inch specimen an elongation of not less than 25 per cent; shearing strength 45,000 pounds per square inch. The weight of mild steel is about 480 pounds per cubic foot. As the upper end of the ingot is likely to be the poorest the test strips should be cut accordingly, although ingots may be cast from below, thereby tending to cause the bubbles to be distributed. A strip from $\frac{3}{4}$ inch to 1 inch wide should be bent double both hot and cold without developing flaws or cracks, for thin plates; and thick plates should withstand bending to a small radius.

Steel does not lend itself readily to welding for one reason, because with varying amounts of carbon in the two pieces the welding temperatures of the two, vary; and then, too, it is difficult to make a weld with a certainty of preserving the strength. Plate that is to be used for flanging must be of the best, and is frequently referred to as fire-box plate. It is not essentially different from shell plate, other than that it is given every care in the making. A fire-box, in addition to requiring special flanging, is subjected to inequalities in expansion, due to air drafts and changes of shape in the shell; a locomotive boiler is also subject to racking.

Mild steel has the uncomfortable peculiarity of becoming brittle at a blue heat temperature. Great care should be exercised in flanging, etc., not to work steel at this temperature. At a bright

red heat, bending, flanging, and forging may be carried on, but after cooling below redness no further work should be done until the material is cold. Mild steel will stand bending hot and cold.

Rivets, whether of steel or wrought iron, should admit of having the tail hammered down hot to form a disc $2\frac{1}{2}$ times the diameter of the shank; and the shank should admit of being hammered flat cold, and having a hole equal to the diameter of the shank punched, without cracking.

Copper. This metal is softer than wrought iron or steel, and has a lower tensile strength, about 34,000 pounds per square inch, but is very ductile and is a good conductor of heat. It has been extensively used in Europe for fire-boxes and steam and water piping, for it may be flanged and bent very readily, and it resists corrosion well. If hammered cold it loses ductility, which may, however, be restored by annealing. The brazed joints in pipes have caused trouble from explosions, for the brazing is more or less unreliable and there may be a great reduction in strength. Wrought iron piping is now favored for high-pressure work. With the strength above quoted, copper should show an elongation of not less than 20 per cent. One cubic foot of copper weighs 558 pounds.

Composition. Copper and zinc in parts 70 to 30 respectively form brass. The higher the brass in copper the redder it will be and also the more valuable; increasing the zinc makes it more yellow. Lead is used as an adulterant.

Bronze is an alloy of copper and tin, in proportions ranging from 8 of tin and 92 of copper for soft bronze to 20 of tin and 80 of copper for bell metal. There are special bronzes, as, for example, phosphor bronze, aluminum bronze, and others.

Locomotive smoke tubes are sometimes made of brass; and this material is often used in gages, cocks, valves, etc. Safety valve seats may be made of bronze with advantage.

Effect of Temperature. The effect of raising the temperature is to weaken the strength of metals, but no appreciable change occurs until after passing 400° Fahrenheit, and the temperature of steam at 150 pounds gage pressure is about 365° F. (For gage pressure of 200 pounds the temperature of saturated steam is 387+°). Wrought and cast iron and mild steel do not become dangerous until a temperature of 750° or more is reached, so that the ordinary pressures do not give rise to any danger, but it should be borne in mind that after all 750° is not a very high temperature to attain should there be any foreign substance deposited within the boiler; in such a case the heat is not doing its proper work, that is, evaporating the water as it should, and the metal becomes overheated. The temperature of the fire is, of course, much higher than the above-mentioned temperature.

DETAILS OF CONSTRUCTION.

Stay Bolts. Suppose the stay bolts supporting the inner sheet, which forms the sides of the fire-box, are spaced 5 inches apart. With steam pressure of 150 pounds per square inch we have

$$(5)^2 \times 150 = 3{,}750 \text{ pounds per bolt.}$$

As these stay bolts are threaded we must take the cross-section at the bottom of the thread. If the diameter in this case is $\frac{8}{16}$ inch, then the area is about $\frac{1}{2}$ square inch. The stress is, therefore,

$$3{,}750 \div \tfrac{1}{2} = 7{,}500 \text{ pounds per square inch.}$$

This is a perfectly allowable load; in fact, it is a low load, but we must consider that there is corrosion to allow for, and the fire-box is likely to have uncertain stresses due to unequal expansion, so that we have not as much of a margin as it at first seems. In the case of stay rods the ends are often upset or made larger in diameter to allow for the depth of the thread. This is frequently called a plus thread. A stay bolt would not save enough in material to pay for this upsetting, and is generally uniform in diameter, being threaded the whole length. After being turned into place the ends are headed over. Sometimes stay bolts crack inside, in which case the load is thrown on the neighboring bolts, and there is at first little indication of such failure externally. For this reason they are sometimes made hollow, so that if they fail, the leakage of steam and water gives notice of the fact.

In certain cases nuts are used on the ends of stays, instead of riveting the ends. Through stays take care of the flat surfaces above the tubes in a multitubular or similar boiler, and the tubes expanded into the tube sheets support them below. Sometimes it is considered necessary to give this lower portion of the tube

sheet additional support. This is accomplished by threading the ends of a portion of the tubes, distributing them so as to take care of the tube sheet, and putting nuts on the outside, or possibly both sides of the tube sheet. Where the tubes are screwed into the tube sheets as well, one end must be larger than the other to allow the tube to be passed in and entered into its tube sheet just before the other end catches. See Fig. 9.

If the stay tubes are to take the whole of the pressure on their portions of the tube sheets, then let

p=steam pressure by gage,
S=surface supported by one tube.

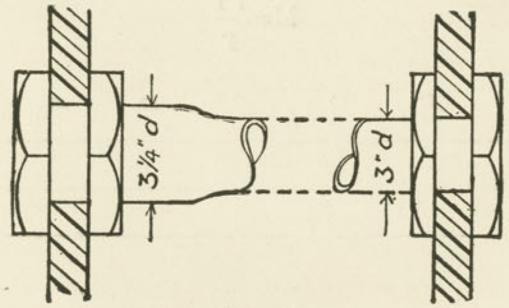


Fig. 9

In this case S will be equal to the rectangle assigned to one tube, less the area occupied by the tubes in that section; then will

p S=the load on one stay tube,
let f_t=tensile strength of the tubes in pounds per square inch,
d_1=the outside diameter at the bottom of the thread,
d_2=the inside diameter of the tube,
then π=the usual symbol expressing ratio of circumference to diameter, 3.1416,

$$f_t = \frac{pS}{(d_1^2 - d_2^2)\frac{\pi}{4}}$$

and f_t should not be allowed to go above the safe working load of the material.

In most cases of stationary boilers at least, the grip of a tube on the tube sheet, due to its expansion, is sufficient to take care of this stress.

Girder Stays. On Plate I will be found a form of girder stay for the top of a fire-box or combustion chamber. With bearings on the ends, we have the case of a beam supported at the ends, the loads being concentrated at definite points. A sample case will show the method of calculation.

With symmetrical loading and $P=P_1=P_2$, Fig. 10, the maximum bending moment will be at the center; then

$$M=\frac{fI}{y}$$

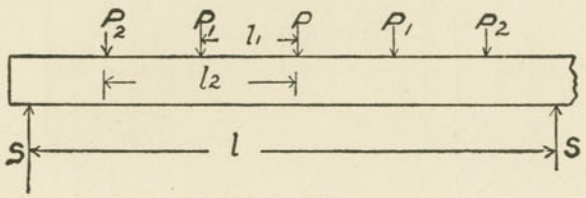


Fig. 10

M=maximum bending moment,
f=modulus of rupture,
I=moment of inertia of cross-section,
y=distance of most strained pipe from neutral axis ($\frac{1}{2}$ the depth of the girder if rectangular).

Load on supports will be

$$P_2+P_1+P+P_1+P_2=5\ P.$$

Load on each support $\frac{5P}{2}$. Taking moments about P (distant $\frac{l}{2}$ from S) we have $\frac{5P}{2}\times\frac{l}{2}-P_1l_1-P_2l_2=M$

For rectangular cross-section of the girder $I=\frac{1}{12}bh^3$

where b=breadth of section,
h=depth of section.

Portions of girders staying the flat heads act as continuous girders. Such cases indicate the extent to which a study of the beam theory could be carried, and a discussion of boilers is scarcely the place for it.

Staying Flat Surfaces. The flat surface in the head of a multitubular boiler, or the crown sheet or sides of the fire-box in a locomotive type boiler (see Plate I), presents the problem of a surface under pressure and supported in different points, which divide the surface into rectangular panels. There is a complete solution for this case only where the panels are squares; but if we calculate the stresses upon the assumption of squares and then make one dimension of the rectangle less, we shall be within the fibre stress as figured for the square.

In *Machine Design* Unwin gives the following formula:

$$f=\frac{2}{9}\frac{a^2}{t^2}p$$

where p=steam pressure,
t=thickness of plate,
a=pitch of stays,
f=working stress, tension in some places and compression in others,

all linear measurements being in inches and pressures in pounds. Where there is a direct tension or compression proper allowance must be made for it.

If in a locomotive fire-box (see Plate I) we have the plate at thinnest point $\frac{5}{16}$ inch thick and steam pressure 150 pounds per square inch, then the rivets being 4 inches apart we have

$$f=\frac{2}{9}\frac{4\times4}{\frac{5}{16}\times\frac{5}{16}}150=5461$$

Suppose that the crown bars carry part of the load through bearings at the ends, to the end sheets, then the area of the crown sheet being

$$28\times 36\tfrac{3}{4}=1,029 \text{ square inches,}$$

the total pressure would be

$$150\times 1,029=154,350 \text{ pounds.}$$

One-half would be carried by each end of the crown bars, so that without assuming any of the load to be carried by the sling bars, remembering that the cross-section of the plate is $28''\times\frac{5}{16}''$, we have

$$\frac{154,350}{28\times\frac{5}{16}}\times\frac{1}{2}=8,820 \text{ pounds per square inch}$$

and this should be added to the stress before figured; we have

$$5,461+8,820=14,281 \text{ pounds per square inch}$$

total compression on this portion of the plate. This illustration serves to show that while the formula

$$f=\frac{2}{9}\frac{a^2}{t^2}p$$

is perfectly simple, yet using it without knowing how it is obtained, and that it does not of necessity take care of *all* the stresses, may lead to gross errors. Each case should be very carefully analyzed to be sure that all the stresses acting are considered. In this case in hand it was assumed that the crown bars carried their part of the load to the sheet in a distributed form, whereas, if there were bearing blocks under the ends, they carried the load to the plate, or the ends of the crown bars were fitted around the lap joint, so that the compression concentrated both in the ends of the bars and on the plate should be considered. It may be said, however, that with the crown sheet lapped over and the end sheet flanged they are in a good position to take care of this load.

Diagonal Stays. Many boilers, in place of the through stays, have rods running diagonally from the heads to the shell. If *o c*, Fig. 11, represents the load that would be supported by a direct or through stay, then will *o d* be the pull along the diagonal stay. Or

$$o\ d=o\ c\div\text{cosine } c\ o\ d.$$

If a stay takes hold of the tube sheet two and a half feet below

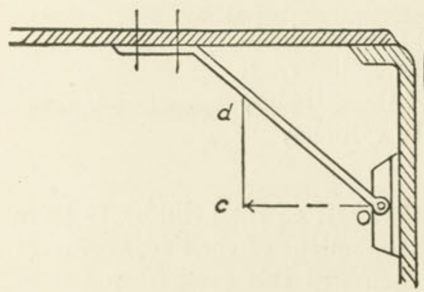


Fig. 11

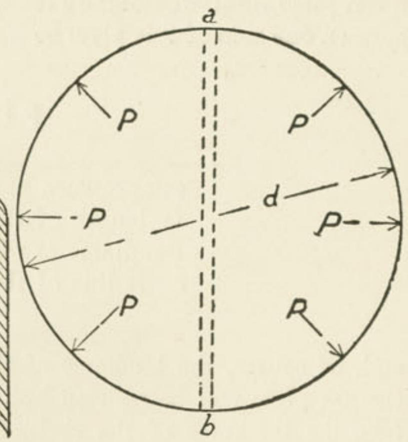


Fig. 12

the point of intersection of the tube sheet surface and top of the shell, and is riveted to the shell five feet back of this point, then we shall have

$$\cos cod=\frac{5}{\sqrt{\left(\frac{5}{2}\right)^2+5^2}}$$

and the pull along *o d* will be the pull along *o c* multiplied by

$$\frac{\sqrt{\left(\frac{5}{2}\right)^2+5^2}}{5}=1.12$$

or twelve per cent more than the direct pull.

In any form of stay it is a matter of importance that the adjustments be so made that each stay carries its portion of the load, otherwise too much load is thrown on one or more of the stays.

Shell. The shell of a boiler is considered as a thin hollow cylinder, for the thickness of the shell is small compared with the diameter of the boiler.

If in Fig. 12 we have a cylinder containing fluid under pressure, then this pressure will act in the directions shown by arrows *P*, normal to the surface of the cylinder. If, now, we imagine a flat plate inserted along a diameter, as at *a b*, then will the pressure on one side of this plate be

$$p\,l\,d$$

p=pressure per square inch,
l=length of the cylinder,
d=diameter of the cylinder,
r=radius of the cylinder,

and, of course, the tendency of that half of the cylinder to leave the flat plate will be resisted by the sections of shell adjacent. If t be the thickness of the shell, then will this pressure $p\ l\ d$ be resisted by $2\ l\ t$.

If f=the working strength of the metal in pounds per square inch, we shall have

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

To find the stress in a ½-inch plate, the diameter of the shell being 66 inches, with the pressure at 150 pounds per square inch, we would have

$$f=\frac{150\times\frac{66}{2}}{\frac{1}{2}}=9{,}900 \text{ pounds per square inch,}$$

which is not unfair for mild steel of good quality. It means that there would be a factor of safety of about 6.

To find the thickness of the shell with the following data:

Pressure, 120 pounds per square inch;
Ultimate strength of steel, 55,000 pounds per square inch;
Diameter of shell, 7 feet;
Factor of safety, 6;

$$t=\frac{p\,r}{f}\qquad \frac{120\times\frac{7}{2}\times 12}{\frac{55000}{6}}=0.55 \text{ inches.}$$

Pressure on Cylinder Ends. The tension set up in a circumferential ring of the cylinder may be found as follows: Using the same letters as before, the total pressure on the end, assuming it to be closed by a flat plate, will be p times the area of a circle of diameter d, or

$$p\times\frac{\pi d^2}{4}=p\times 0.7854\,d^2$$

This pressure must be resisted by a ring of metal whose length is the circumference of the shell and thickness t; the stress per unit section being V, then $\pi\ d\ V\ t$=resistance of the ring; then

$$\pi\,d\,V\,t=\frac{p\,\pi\,d^2}{4}$$

$$V=\frac{d\,p}{4\,t}=\frac{p\,r}{2\,t}$$

Now, the stress in the longitudinal direction is

$$\frac{p\,r}{t}$$

therefore, the shell being made of homogeneous material and uniform will be subject to but one-half the stress from end tension as from ring tension. It makes no difference to the shell how the ends are closed, whether by flat plates or those of any other form.

A thin hollow sphere would be figured the same as a thin hollow cylinder for internal pressure. In some cases a boiler is fitted with bumped heads, where the edges are flanged to make a joint with the shell.

Welded Joint. While a welded joint appears neat and workmanlike, it is uncertain as to strength. It will answer very well, for example, in tubes, but for a shell joint would be open to criticism. The remarks concerning the welding properties of wrought iron and steel should be borne in mind in this connection.

Rivet Holes. The form of joint most used is that made by

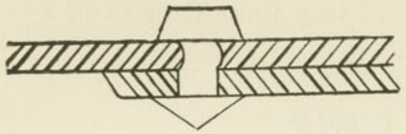


Fig. 13

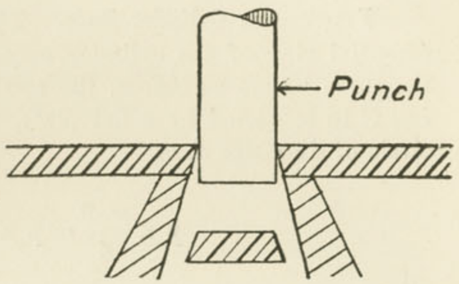


Fig. 14

cutting holes near the edges of the plate and riveting the plates together. These holes may be punched or drilled. Several forms of punch are used, one having a straight square face, another with a center point, and a third having a helical cutting surface. In any case the punching has a tendency to break and tear the portion of plate around the holes and does not give nearly as good a job as drilling. Then, too, punching must be done with the plate flat, so that any error in laying out the holes spoils their alignment when the plate is rolled. A drift pin that is somewhat smaller than the hole, being tapered at both ends, is driven through, but this is a poor makeshift at the best. The result is that the rivet when driven is very much like Fig. 13. Sometimes the holes are punched small and then drilled to size; with the modern gang

drills there is no reason why any but holes drilled in place should be used. Soft ductile plates are injured less than hard ones in punching, and, in general, steel plates stand punching better than wrought iron. Another difficulty with punching is that as the punch forces its way through the metal the diameter of the piece

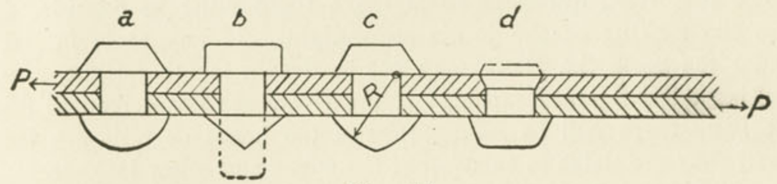


Fig. 15

punched out is larger on the further side of the plate than where the punch face bears, as in Fig. 14.

Fig. 15 shows several forms of driven rivets. The tails of the rivets are on top.

a. Pan tailed, head formed with die or snap.
b. Flat tailed, head hammer-driven.
c. Pan tailed, head machine-driven.
d. Counter-sink tailed; any head may be used and the tail may project slightly above the plate as dotted.

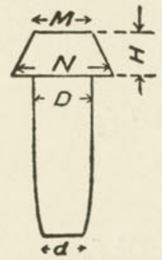


Fig. 16

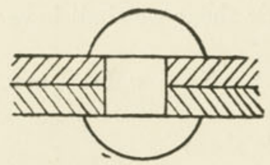


Fig. 17

Sometimes the rivets have conical necks, and with the conical-shaped holes made by punching, the plates should be so placed that the smaller diameters of the holes come together. Good proportions for rivets are as follows (Fig. 16), D being the diameter of the shank:

N=1.4 to 1.5 ×D
M=1.2 to 1.3 ×D
H=0.67 to 0.7 ×D
d=0.75 to 0.93×D

Fig. 17 is a sample of an eccentric head.

Aside from questions of strength there must be considered also the making of the joints steam-tight. If any scale is left under the head, the plates may not be drawn together tight, preventing a good job of calking; if the rivets are not driven to fill the holes there will be leakage; when the heads or tails are too small they are liable to turn up at the edges and allow leakage.

Single and Double Shear. Rivets holding together portions of plate with pull in opposite directions, as P and P in Fig 15, are said to be in single shear. Where a rivet connects three layers of plate, the two outer ones under tension in one direction, the middle plate being pulled in the opposite direction (see Fig. 18), the rivet is under double shear. As this situation tends to shear the shank of the rivet in two places, the resistance is twice as great as for a rivet in single shear.

Let D=diameter of rivet in inches,
f_s=shearing strength of the material in pounds per square inch,
S=total resistance.

Then for single shear we shall have

$$S=\tfrac{1}{4}\pi D^2 f_s=0.7854 D^2 f_s$$

and for double shear

$$S=2\times\tfrac{1}{4}\pi D^2 f_s=1.5708 D^2 f_s$$

Gripping Power of Rivets. The friction between the plates due to the grip of the rivets is a considerable amount, given by some authorities as much as $\frac{2}{3}$ of the tensile strength of the rivet. But this holding power should not be relied upon, because slipping occurs very soon after applying the load.

Riveted Joints. Several forms of riveted joints will be shown

and discussed. In none of them will the strength be found to be up to that of the solid plate, but for high-pressure work a high efficiency can be obtained. Here, as in so many other places, the efficiency of the design is one thing and the efficiency of the execution quite another, unfortunately. When a rivet is once driven little or no evidence remains to indicate if the holes came fair; if the plate was damaged in cutting the hole; if the rivet filled the hole; if any dirt or scale was occluded; if the rivet shank was overheated, etc. If there be any defect it will surely not grow better, and some day it may contribute to disaster. Nothing short of absolute honesty in its broadest sense should be tolerated in such construction.

There is some reason in using iron rivets with iron plate, and steel rivets with steel plate, etc., for galvanic action takes place between dissimilar metals and little or none between like

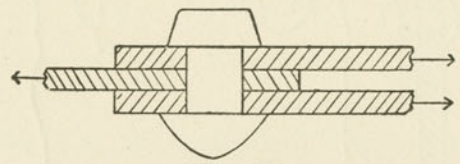


Fig. 18

metals. The amount of damage coming from iron rivets in steel plate is, however, small and almost negligible. Between copper and iron there would be much more action.

Crushing may take place between the rivet and the portion of the plate bearing on it. It is customary to figure the area that resists crushing as a rectangle, whose height is the thickness of the plate and breadth the diameter of the rivet. In Fig. 19 A represents the rivet with head cut off. The pull in the plate will be resisted along the palallel lines *c, d, e*. The line *d* at the center is the only one normal to the edge of the hole, while all others, as *c* and *e*, have oblique bearing surfaces. As a matter of fact, experiments on crushing show an apparent strength of 90,000 to 100,000 pounds per square inch bearing surface, when so calculated, which is, of course, high as compared with other strength figures.

Lap is the width of the strip of plate measured from the center of the rivet hole to the edge of the plate. The distance from the edge of the rivet hole to the edge of the plate should be rather greater than the rivet diameter.

FORMS OF RIVETED JOINTS.

Peabody and Miller in *Steam Boilers* include the following cases among others:

Lap Joint Single-riveted. Fig. 19 represents such a joint.

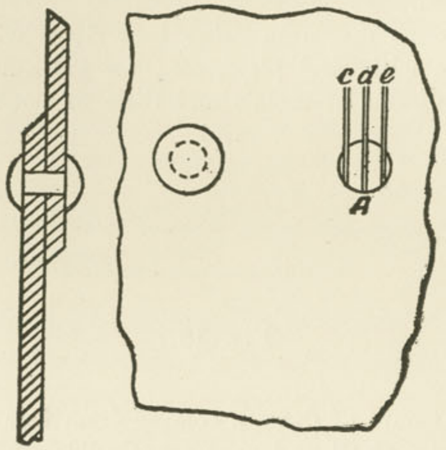


Fig. 19

Let the thickness of the plate be t, the diameter of the rivet d, and the pitch p (this is the distance of one rivet from another measured from center lines). For strengths take (all linear measurements being in inches.)

f_c	(crushing)	95,000
f_s	(shearing)	45,000
f_t	(tensile)	55,000

With $t=\frac{1}{2}''$, $p=2\frac{1}{4}''$, $d=\frac{7}{8}''$, we shall have for crushing

$f_c\ t\ d=95{,}000\times\frac{1}{2}\times\frac{7}{8}=41{,}560$

For shearing area one rivet$=\frac{\pi}{4}\times(\frac{7}{8})^2$

$$0.7854\times\frac{7}{8}\times\frac{7}{8}\times45{,}000=27{,}045$$

The resistance to tearing between the rivet holes will be $f_t\ (p-d)\times t$

$$55{,}000\ (2\tfrac{1}{4}-\tfrac{7}{8})\ \tfrac{1}{2}=37{,}813.$$

The strength of a piece of plate $2\frac{1}{4}$ inches wide will be

$$55{,}000\times2\tfrac{1}{4}\times\tfrac{1}{2}=61{,}875.$$

Taking the shearing strength. this being the lowest of the three, the apparent efficiency of this joint will be

$$\frac{27{,}045}{61{,}875}\times100=43.7 \text{ per cent.}$$

This is a low value, and in a practical case it would be better to increase the size of the rivet relatively to the thickness of the plate. If a $\frac{1}{2}$-inch plate must be used on account of the pressure to be carried, then, of course, a larger rivet should be used. A one-inch rivet would give under these conditions

$$100\times\frac{\frac{1}{4}\pi d^2\times f_s}{p\times t\times f_t}=57+\text{per cent and }100\times\frac{(p-d)t\times f_t}{p\times t\times f_t}=56 \text{ per cent.}$$

Some advantage might be claimed in the case of tearing, in that short-necked specimens show higher strength per square inch of section than solid plate, but it is not necessary in this case to claim it. It is not difficult to proportion a joint properly without this.

Lap Joint Double-riveted. If the rivets are in line as at A, Fig. 20, it is called *chain riveting;* if as at B *zigzag* or *staggered.* This joint may fail if the upper row of rivets is too close to the lower row by tearing zigzag between the rivet holes; but the more usual failures will be in one of the three following ways:

1. Crushing in front of rivets, using 1″ rivets and $2\frac{1}{2}$″ pitch; $f_c \times 2d \times t = 95{,}000 \times 2 \times 1 \times \frac{1}{2} = 95{,}000$.

2. Tearing between two rivets; $f_t\ (p-d)\ t = 55{,}000\ (2\frac{1}{2}-1)\ \frac{1}{2} = 41{,}250$.

3. Shearing two rivets; $2 \times \frac{\pi d}{4} \times 45{,}000 = 2 \times 0.7854 \times 45{,}000 = 70{,}686$.

The lowest value is for tearing, the apparent efficiency being

$$100 \times \frac{41{,}250}{68{,}750} = 60 \text{ per cent.}$$

Here it is seen that the increase in efficiency between these

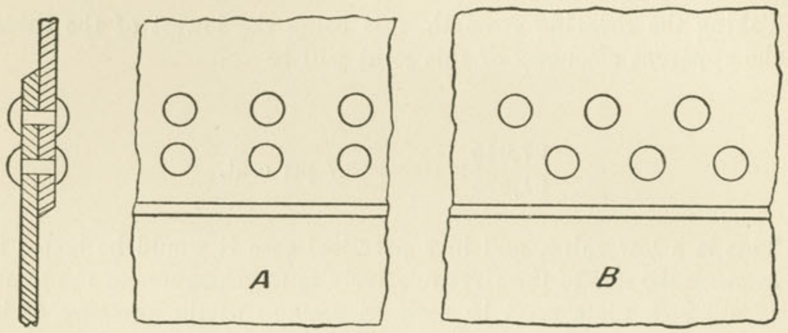


Fig. 20

two types of joint comes from increasing the pitch and decreasing the size of the rivet. Three rows of rivets might be used, but the pitch is limited by the fact that as the distance between rivets increases for a given thickness of plate a limit is reached, beyond which a good job of calking cannot be secured.

Lap Joint, One Cover Plate. Here P, the pitch of the outer row of rivets $= 2\ p$, the pitch of the inner row, Fig. 21.

Assume dimensions as follows: Thickness of plate $t = \frac{3}{8}$ inch; cover plate the same; diameter of rivet $d = \frac{13}{16}$ inch.

$P = 4$ inches,
$p = 2$ inches,
$f_c = 95{,}000$,
$f_s = 45{,}000$,
$f_t = 55{,}000$.

1. Tearing plate between rivets in outer row;

$$f_t\ (P-d)t = 55{,}000(4-\tfrac{13}{16})\tfrac{3}{8} = 65{,}700.$$

2. Tearing plate between rivets at inner row, shearing outer rivets;

$$f_t(P-2d)t + f_s\tfrac{1}{4}\pi d^2\ 55{,}000\ (4-2\times\tfrac{13}{16})\ \tfrac{3}{8} + 45{,}000 \times 0.7854 \times (\tfrac{13}{16})^2 = 72{,}260.$$

3. Shearing three rivets; $f_s \times 3 \times \frac{1}{4}\pi d^2$

$$45{,}000 \times 3 \times 0.7854 \times (\tfrac{13}{16})^2 = 70{,}000.$$

4. Crushing in front of three rivets; $f_c \times 3 \times d \times t$

$$95{,}000 \times 3 \times \tfrac{13}{16} \times \tfrac{3}{8} = 86{,}830.$$

5. Plate tearing between rivets at inner row, and crushing in front of one rivet in outer row; $f_t\ (P-2d)t + f_c dt$

$$55{,}000\ (4-2\times\tfrac{13}{16})\tfrac{3}{8} + 95{,}000 \times \tfrac{13}{16} \times \tfrac{3}{8} = 77{,}975.$$

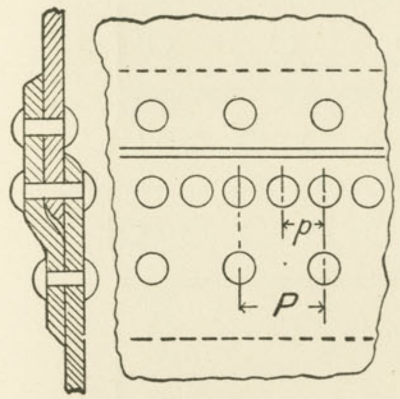


Fig. 21

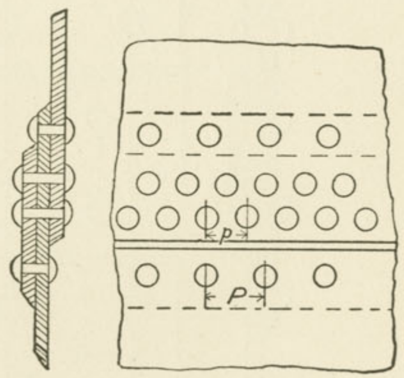


Fig. 22

The lowest value above obtained is the first, hence an apparent efficiency will be

$$100 \times \frac{f_t\ (P-d)\ t}{f_t \times P \times t} \text{ or } 100 \times \frac{P-d}{P} = 79.7 \text{ per cent.}$$

for $f_t \times P \times t$ is the strength of a piece of plate before cutting any rivet holes.

Double-riveted Lap Joint and Cover Plate.* A double-riveted lap joint with cover plate may yield as follows, Fig. 22:

1 Tearing at the rivets along inner row and crushing in front of one rivet, using letters as before; $f_t\ (P-\frac{3}{2}d)\ t + f_c dt$.

2. Crushing before four rivets; $f_c 4dt$.

* Remember, lap joints are not used in good practice. These examples are for instruction merely.

3. Plate tearing along inner row of rivets and shearing outer row of rivets; $f_t\,(P-\frac{3}{2}d)\,t+f_s\frac{1}{4}\pi d^2$.
4. Shearing four rivets; $f_s 4\times\frac{1}{4}\pi d^2$.
5. Plate tearing between rivets at outer row; $f_t\,(P-d)\,t$.

As this last case is apt to be the weakest, an estimate of its value may be had quickly in finding the efficiency as follows:

$$\frac{P-d}{P}\times 100=\text{efficiency}.$$

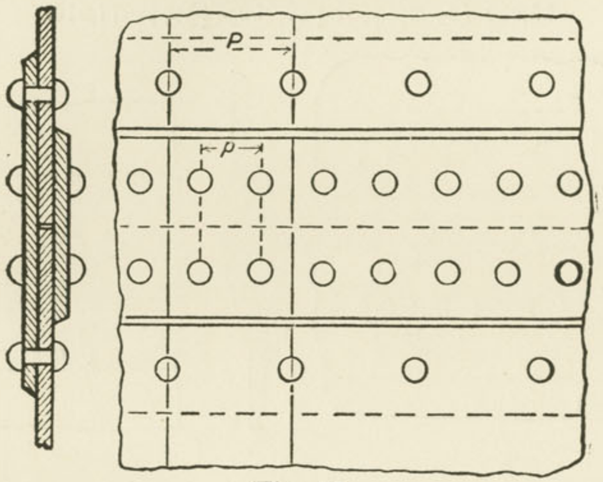


Fig. 23

Butt Joint Double-riveted. Fig. 23 represents such a joint. It may fail as follows:

1. Shearing two rivets in double shear and one in single shear;

$$f_s\times 5\times\frac{1}{4}\pi d^2.$$

2. Tearing the plate between rivet holes on inner row and shearing one outside rivet; $f_t\,(P-2d)\,t+f_s\frac{1}{4}\pi d^2$.
3. Crushing in front of three rivets; $f_c\times 3dt$.
4. Crushing in front of two rivets and shearing one rivet:

$$f_c 2dt+f_s\frac{1}{4}\pi d^2.$$

5. Plate tearing between rivet holes on outer row; $f\,(P-d)\,t$.

Butt Joint, Two Cover Plates, Triple-riveted. This joint may be figured in the five following ways, using the same letters as before:

1. Shearing one rivet, single-shear, and four rivets double-shear; $f_s\,\{(2\times 4)+1\}\,\frac{1}{4}\pi d^2$.
2. Tearing plate at middle row of rivets and shearing one rivet; $f_t\,(P-2d)\,t+f_s\times\frac{1}{4}\pi d^2$.
3. Shearing one rivet and crushing in front of four; $f_s\times\frac{1}{4}\pi d^2+f_c\times 4dt$.

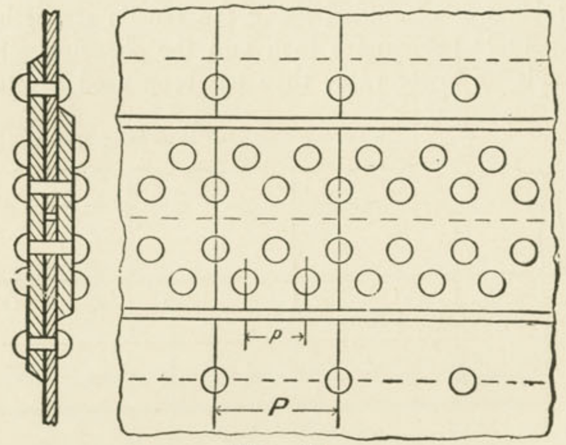


Fig. 24

4. Crushing before five rivets; $f_c\times 5\times dt$ if the cover plates are of the same thickness as shell. If the inner cover plate is thinner then we shall have $f_c\times 4\times dt+f_c\times d\times$ thickness inner cover.
5. Tearing plate between rivet holes in outer row; $f_t\times(P-d)\,t$.

There are, of course, many variations from the foregoing, but these examples illustrate the principles involved, and other cases may be solved thereby.

In designing a quadruple-riveted joint with butt straps, the same general reasoning will apply as in the preceding cases. The row B is usually spaced midway between row A and the edge of the outside cover plate. Care should be taken that rows A and B are sufficiently far apart so that the plate may not tear zigzag.

The following table gives proportions which have been used with good results (refer to Fig. 24a):

T	t	d	P_1	P	p	l	O	I	% e
$\frac{7}{16}$	$\frac{3}{8}$	$\frac{7}{8}$	15	$7\frac{1}{2}$	$3\frac{3}{4}$	$1\frac{5}{16}$	$9\frac{3}{4}$	$19\frac{1}{2}$	94
$\frac{1}{2}$	$\frac{3}{8}$	$\frac{15}{16}$	$15\frac{5}{8}$	$7\frac{13}{16}$	$3\frac{29}{32}$	$1\frac{13}{32}$	$10\frac{5}{16}$	$20\frac{11}{16}$	94
$\frac{9}{16}$	$\frac{7}{16}$	$\frac{15}{16}$	$15\frac{11}{16}$	$7\frac{27}{32}$	$3\frac{59}{64}$	$1\frac{13}{32}$	$10\frac{5}{16}$	$20\frac{11}{16}$	94
$\frac{5}{8}$	$\frac{15}{32}$	$1\frac{1}{16}$	$15\frac{1}{2}$	$7\frac{3}{4}$	$3\frac{7}{8}$	$1\frac{19}{32}$	11	$22\frac{5}{8}$	93
$\frac{11}{16}$	$\frac{17}{32}$	$1\frac{3}{16}$	$15\frac{5}{8}$	$7\frac{13}{16}$	$3\frac{29}{32}$	$1\frac{25}{32}$	$11\frac{13}{16}$	$24\frac{11}{16}$	92.4
$\frac{3}{4}$	$\frac{9}{16}$	$1\frac{3}{16}$	$15\frac{1}{2}$	$7\frac{3}{4}$	$3\frac{7}{8}$	$1\frac{25}{32}$	$11\frac{3}{4}$	$24\frac{5}{8}$	91

This table was computed using the tensile strength of steel as 55,000 pounds per square inch and the shearing strength as 42,000 pounds—a lower value than has been used heretofore.

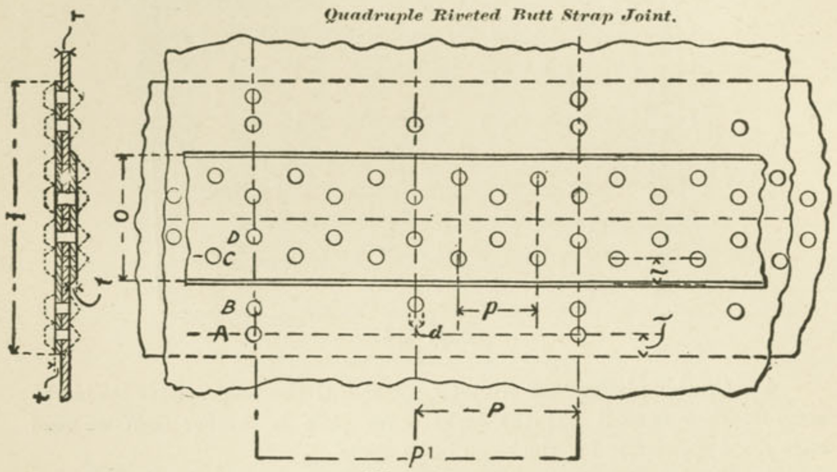


Fig. 24*a*

T=thickness of shell plate,
t=thickness of cover plate,
d=diameter of rivet hole,
P_1=pitch of outside rows of rivets,
P=pitch of third row of rivets from joint,
p=pitch of inner rows of rivets,
l=laps of cover plates,
O=width of outside cover plate,
I=width of inside cover plate,
e=efficiency of joint.

General. It may be said in a general way that calking, or rather the question of keeping a joint tight by calking, limits the pitch for a given thickness of plate. It is customary to calculate the thickness of the shell plate directly from the pressure. Thus the line or lines of rivets along calking edges are fixed approximately very readily. From the preceding examples it is seen that frequently the efficiency of a joint depends upon the ratio of the strength of the plate remaining after cutting the outer row of rivet holes, to the solid plate. Where a high efficiency is wanted, therefore, the pitch for this row of rivets must be kept large, and the strength in other particulars made up by the inner rows. In a single-riveted lap joint the resistance to shearing may be equated to the resistance to crushing to find the diameter of the rivet.

$$f_c dt = f_s \times \tfrac{1}{4}\pi d^2$$

$$d^2 = \frac{4 f_c dt}{f_s \pi}$$

$$\therefore\ d = \frac{4 f_c t}{f_s \pi}$$

In case of steel plates $\frac{1}{2}$ inch thick we would have

$$d = \frac{4 \times 95{,}000 \times \frac{1}{2}}{45{,}000 \times 3.1416} = 1.34 \text{ inches.}$$

Equating the tearing and shearing resistances we have

$$f_t\,(p - d)\,t = f_s \tfrac{1}{4}\pi d^2$$

$$p = \frac{f_s}{f_t}\,\frac{\pi d^2}{4t} + d$$

$$= \frac{45{,}000}{55{,}000} \times \frac{3.1416 \times 1.34^2}{4 \times \frac{1}{2}} + 1.34 = 3.64 \text{ inches.}$$

As before deduced, the efficiency is

$$\frac{p - d}{p} = \frac{3.64 - 1.34}{3.64} = 0.63,$$

or 63 per cent.

In a double-riveted lap joint the result of equating the shearing and crushing for two rivets gives

$$f_c \times 2dt = f_s \times 2\frac{\pi}{4}d^2$$

$$\text{or } d = \frac{4t}{\pi}\frac{f_c}{f_s}$$

the same result obtained in the case of the single-riveted lap joint.

Often a rivet diameter is chosen and the pitch determined by equating the shearing resistance of two rivets to the tearing resistance between the rivets.

The figures representing the ultimate strengths of the materials used are, of course, averages; and the yield points or elastic limits are subject to an uncertainty, so that often, where, in using the foregoing formula, the results are apparently disproportionate we are justified in making certain changes, having in mind the problem as a whole. For instance, the steam pressure tends to lift the plate between rivets, causing leakage; if the plates lap the one on the other perfectly, there is no opportunity for the steam to get into the joint, but we know that in all cases the outer edge must be calked. So that here several factors may enter when we are determining the pitch: for instance, the workmanship; the care exercised in making the joint and freeing it from scale before making up; the lateral stiffness of the plates, whether for a stationary or other boiler, remembering that the former are not subject to racking and straining, which tend to start joints in the latter; and thus other considerations could be named.

We know that a necked specimen, similar to the condition of the plate between the rivet holes, is stronger per unit of area than the solid plate. While we would rather not use a higher value of f_t in the first instance, still it may not be out of reason to take this into account in some cases when we are adjusting our proportions.

In the case of a lap joint, single riveted with one cover plate, we may find the minimum diameter of rivets by equating the resistance to tearing the plate at the outer row of rivets to the

resistance to tearing the plate at the inner row of rivets, plus the resistance to shearing of one rivet at the outer row.

Let P=pitch at outer row,

p=pitch at inner row$=\frac{P}{2}$

d=diameter of rivet,

t=thickness of plate,

f_s=resistance to shearing one square inch,

f_c=resistance to crushing one square inch,

$$f_t(P-d)t = 2f_t(p-d)t + f_s\tfrac{1}{4}\pi d^2$$

$$f_t(P-d)t - f_t(P-2d)t = f_s\tfrac{1}{4}\pi d^2$$

$$f_t dt = f_s\tfrac{1}{4}\pi d^2$$

$$\therefore d = \frac{4f_t t}{f_s \pi}$$

It will be proper to choose rivets rather larger in diameter than this would give; for example, let $t=\frac{1}{2}$ inch, then

$$d = \frac{4 \times 55{,}000 \times \frac{1}{2}}{45{,}000 \times 3.1416} = 0.78 \text{ inch.}$$

Now, we might take a $\frac{13}{16}$-inch or even a $\frac{7}{8}$-inch rivet and find the corresponding pitch by equating the resistance to tearing at the outer row of rivets to

1. The resistance to shearing of three rivets.
2. The resistance to crushing in front of three rivets.
3. The resistance to tearing the plate between the rivets at the inner row and crushing in front of one rivet.

Whichever of these three calculations gives the smallest pitch indicates the figure to be used. The joint should, of course, be examined as to its other details, and if in changing one dimension a weakness is developed elsewhere, the proper remedy must be applied. If the diameter of rivets is increased to give a higher shearing resistance, then care must be taken not to allow the resistance to tearing of the plate between rivet holes to be impaired too greatly.

Suggestions. Calking must not be done with a sharp-nosed tool; sometimes a fullering tool will give better results, merely bending the plate slightly, so that the edge bears hard on the plate below, as Fig. 25.

Fig. 26 is an exaggerated example of what may come from

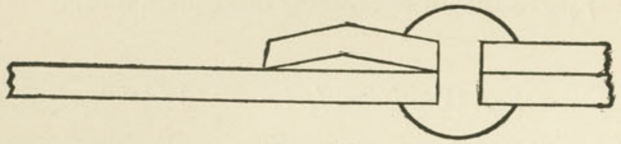


Fig. 25

using a sharp tool. Rivets must be driven; consideration must be given as to how this may be done, whether by hand or by machine, and room allowed to properly set the head. Only whole numbers of rivets can be used; occasions have been when through a ludicrous error, for instance, 151½ rivets have been specified; in laying out a joint it is customary to take the nearest number of rivets to that calculated and space evenly along the joint. Rigidity, in an absolute sense, is sometimes expensive; a certain amount of

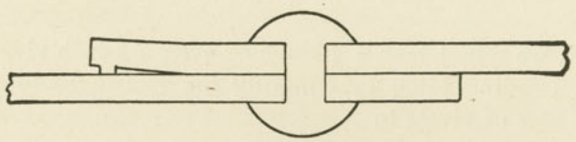


Fig. 26

mobility without loss of strength or efficiency usually means longer life.

Furnace Tubes and Flues. These forms are subjected to external pressure, and are in the opposite stress from the shell, that is to say, they are under compression. We well know that a steel rod will not bear under compression, that is, acting like a column, nearly as much load as it will carry under tension; the value of the fraction decreases as fast as the ratio of length to diameter of

the rod is increased. In fact, at extremes, the rod will not remain upright from its own weight. The tension stress tends to straighten any slight kinks, while compression increases them, and the eccentric loading becomes excessive.

A boiler shell under pressure, if not truly cylindrical, tends to become so, as does the tension rod to straighten, but in a flue under compression the pressure tends to increase the distortion. A true cylinder under external fluid pressure is in a similar condition to one under internal pressure. The thin, hollow cylinder we figured as follows:

$$p\,r = f\,t$$

where p=pressure lbs. per square inch,
r=radius in inches,
f=strength of the material in lbs. per square inch,
t=thickness of the shell in inches.

As the compressive strengths of mild steel and wrought iron are about equal to the tensile strengths, the formula holds good, except as before suggested, namely, that with any initial digression of the figure from the cylindrical shape the tendency of the pressure is to carry it further, even to the point of collapse. Long flues are more liable to this trouble than short ones for the same thickness of material, for the support of the ends is less accordingly. As we increase the thickness of flues to withstand higher pressures, we must remember that with the increased thickness come many chances for flaws in the plates and uncertainties in the welding. One type of corrugated furnace is made by scarfing the edges of a flat plate, rolling it into cylindrical form, welding the edges together by means of a gas furnace and rolls, and finally giving the corrugated form by means of rollers.

The evaporative efficiency of thick plates is but little less than in the case of thin ones, but dirt or scale, if allowed to collect, will soon result in injury to any plate.

Many experiments have been made to determine the strengths of flues, and none are more widely quoted than those made by Fairbairn. The formula deduced by him from the experiments is as follows:

$$p = \frac{806300 \times t^{2.19}}{L \times d}$$

p=collapsing pressure pounds per square inch,
t=thickness of shell in inches,
L=length of flue in feet,
d=diameter in inches.

Ordinarily the thickness of the plate is less than an inch, and the exponent of t is taken as 2 instead of 2.19, thus making the calculated collapsing pressure greater; that is,

$$p=\frac{806300\times t^2}{L\times d}$$

Suppose we have a flue as follows:

Length, 25 feet,
Diameter, 18 inches,
Thickness, ½ inch

Then

$$p=\frac{806300\times(\frac{1}{2})^2}{25\times 18}=448 \text{ pounds per square inch.}$$

Too much dependence must not, however, be placed on this rule, for the results may be higher or lower than the real strength.

In "Steam Boiler Construction" Hutton gives the following table:

Tested by or at	Dimensions of the Experimental Tubes.			Collapsing Pressure of Tube in Pounds per Square Inch.		
	External Diameter in Inches.	Length in Inches.	Thickness in thirty-seconds of an inch.	As found by Fairbairn's Formula using t^2	As found by experiment	As found by Hutton's Formula.
By Fairbairn . . .	7.87	276	5	109	110	114
" . . .	33.5	360	11	81	99	113
" . . .	42	420	12	78	97	100
" . . .	42	300	12	108	127	119
By Chief Engineer U. S. N.	54	36	8	311	128	120
At Greenock . . .	38	86	16	740	450	436
By Knight . . .	36	24	8	700	235	218
"	36	24	12	1568	468	490
"	36	48	12	784	390	350
By J. Howden & Co. .	43	23	17	2758	840	842

The formula proposed by Hutton is

$$\frac{C\times t^2}{d\times\sqrt{L}}$$

t=thickness in thirty-seconds of an inch,
d=diameter, external, in inches,
L=length in inches.

C is a constant which varies with the material. For mild steel C=660. For wrought iron C=600. L is to be taken as the distance between flanges, if the tube or flue be so reinforced.

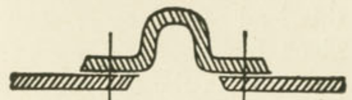


Fig. 27

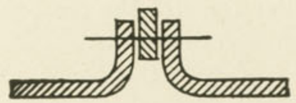


Fig. 28

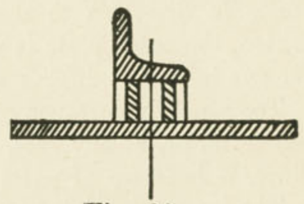


Fig. 29

As steel may lose some of its stiffness by overheating and by the many strains to which it is subjected, it is sometimes figured with the same constant used for wrought iron, viz.: C=600.

If oval tubes are used, the diameter should be taken as that of the greatest circle of curvature.

Example. Find the collapsing pressure of a flue 12 feet long, 30 inches in diameter outside, ⅜-inch thick.

$$\frac{600\times(12)^2}{30\times\sqrt{144}}=240 \text{ pounds per square inch.}$$

Longridge suggests a formula

$$\frac{174{,}000 \times t^2}{D \times \sqrt{L}}$$

where

t=thickness in inches,,
D=external diameter in inches,
L=length in feet,

and this is the same form as Hutton's, but gives a constant somewhat less.

In some special cases the fire-box will be found supported by screw stays, and not treated as a flue. The thickness is by this means kept to $\frac{3}{8}$-inch, the load being carried to the outer shell, which is $\frac{1}{2}$-inch thick. But this load on the outer shell is opposite in direction to the load given by the steam pressure; then, too, the outer plate is not in contact with the fire, while the inner one is, and it affords a good evaporating surface.

Too much importance cannot be given to preserving the cylindrical form, or, at any rate, the circular form of the cross-section of flues, if built up of parts with different diameters.

The lap-welded joint lends itself readily to this shape, and in practice can be obtained with but small digression. A riveted lap joint is very poor for reasons before brought out. The repeated expansion and contraction, to say nothing of the wear of a flue, tend to weaken it faster than other parts of a boiler, so that oftentimes new fire-boxes and flues are fitted to old shells, where the original design is so made as to allow this to be done.

Flues are stiffened in many ways, some of which are as follows: By turning up flanges and sometimes inserting a solid ring, riveting the whole firmly, as in Fig. 27. This is known as the Adamson joint. By riveting on a hoop ring, as at Fig. 28; by riveting on a supporting ring, as at Fig. 29. Then there are flues made with straight and spiral corrugations throughout their lengths.

Lloyd's and United States Rules for Plain Flues. Here we have

$$p=\frac{89{,}600 \times t^2}{L \times d}$$

where p=steam pressure in pounds per square inch,
t=thickness in inches,
L=length in feet,
d=diameter in inches.

Comparing this with Fairbairn's formula, we have the constant 89,600=806,300÷9, or, in other words, a factor of safety of 9, and the exponent of t is 2, rather than 2.19. The use of so large a factor of safety as nine indicates that there is considerable uncertainty in the assumptions, but the chances are that the flue so figured will be amply strong.

The Board of Trade Rule. This rule uses the formula

$$p=\frac{99{,}000 \times t^2}{L \times d}$$

which differs only in the constant 99,000; this assumes a factor of safety of

$$\frac{806{,}300}{99{,}000}=8.1$$

It is required, however, that the presure shall not exceed

$$p=\frac{4{,}400 \times t}{r}$$

p=pressure in pounds per square inch,
t=thickness in inches,
r=radius in inches,

or, in other words, a stress of 4,400 pounds per square inch of metal. For furnaces having corrugations, ribs, or grooves, both the United States' Inspectors and Lloyd's allow a working pressure of

$$\frac{7{,}000 \times t}{r}$$

or, in other words, a stress of 7,000 pounds per square inch under working conditions. *Lloyd's Rule* for such furnaces is found from the equation

$$p=\frac{C\,(T-2)}{D}$$

p=working pressure pounds per square inch,
T=thickness in sixteenths of an inch,
D=diameter in inches measured to the outside of corrugations or ribs,
C is a constant which varies with the style of furnace and strength of the material, as follows:

For steel furnaces corrugated, tensile strength less than 26 tons, corrugations 6 inches apart and 1½ inches deep, C=1,000. For steel furnaces corrugated as in Fox's or Morison's styles, Figs. 30 and 31, tensile strength between 26 and 30 tons, C=1,259. For furnaces with ribs 9 inches apart C=1,160. For furnaces spirally corrugated C=912. Subtracting 2 from the value of T in the formula means that inasmuch as T is expressed in sixteenths of an inch, two-sixteenths or one-eighth of an inch of metal is allowed for wasting away.

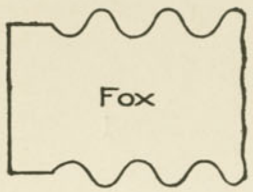


Fig. 30

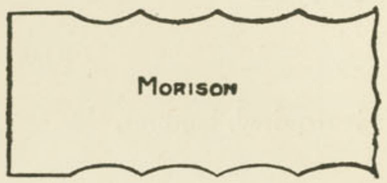


Fig. 31

As our working stress is found from the equation

$$p=\frac{ft}{r}$$

p=pressure pounds per square inch,
f=stress pounds per square inch,
t=thickness in inches,
r=radius in inches.

We find Lloyd's rule to be comparable by multiplying C by 16 and dividing by 2, that is, in the case of the spirally corrugated furnace where C=912, we would have a fibre stress of

$$\frac{912\times 16}{2}=7,296 \text{ pounds per square inch.}$$

Fire Tubes come under the same heading as flues, but the ratio of diameter to length is so small in this comparison that collapsing is almost unknown with the thickness of metal necessary to secure a good joint, and to allow the tube to hold properly when expanded into the tube sheet. The standard dimensions of a few sizes are given:

Diameter.		Thickness.	Wire Gage.	Transverse Area.		Length Per Sq. Ft. Heating Surface.		Weight Per Foot Pounds.
External Ins.	Internal Ins.			External Sq. Ins.	Internal Sq. Ins.	External Feet.	Internal Feet.	
2	1.81	0.095	13	3.14	2.57	1.91	2.11	1.91
2¼	2.06	0.095	13	3.98	3.33	1.70	1.85	2.16
2½	2.28	0.109	12	4.91	4.09	1.53	1.67	2.75
2¾	2.53	0.109	12	5.94	5.03	1.39	1.51	3.04
3	2.78	0.109	12	7.07	6.08	1.27	1.37	3.33
3¼	3.01	0.12	11	8.30	7.12	1.17	1.26	3.96
3½	3.26	0.12	11	9.62	8.35	1.09	1.17	4.28
3¾	3.51	0.12	11	11.04	9.68	1.02	1.09	4.60
4	3.73	0.134	10	12.57	10.94	0.95	1.02	5.47

Factor of Safety. If our knowledge of the strengths of our various materials was accurate and we could foresee the loads, including the incidental with the working loads, we should not need to build boilers as heavy as we do. It will not do, of course, to allow any part to be strained beyond the elastic limit, for thereby the loads will be thrown on other portions in a different manner and with a different intensity from that intended. Then, too, we must bear in mind the methods of and facilities for construction as well as questions of handling, transporting, and erecting. The testing of a boiler under water pressure is carried to some point, often once and a-half the working pressure, and this must not unduly strain any portion, for it may mean the yielding of the part under a much lower pressure when carried continuously for a long time. After all, factors of safety are more or less factors of guess, but we should bear in mind that the greater the damage done by the failure of the part, the greater the reason why we should insure its safety by using more metal. Corrosion and wasting of the metal may be deliberately allowed for in addition to the amount calculated as necessary to carry the load, or the factor of safety may be made larger in such cases. A factor of six undoubtedly allows for deterioration, and is entirely conservative. A factor of four is surely small enough, and should carry with its use a very careful determination of the stresses. Remembering that the elastic limit is in the vicinity of one-half the ultimate strength, and that with a test pressure of one and a-half times the working pressure we are very close to the yield point, a factor of four is on the whole meagre.

With a boiler under careful supervision and close inspection, a factor of five should serve well; there are many boilers in use that were designed with this factor.

Hydraulic Tests. One and a-half times the working pressure is a customary test pressure for new boilers. By this means leaks are discovered and also gross errors either in design or construction. It is better to have the regular fittings on the boiler when tested than to have the openings blank flanged.

All flat surfaces should be carefully inspected while the hydraulic pressure is on, noting carefully any indication of distortion. Cold water pressure is considered to give a very severe test, for it will often show leakage where steam would not. Hot water is sometimes spoken of as giving the proper expansion; but it is a matter of difficulty to secure a thorough inspection, and, on the whole, the cold water test serves very well. As leaks develop they can be calked, either under pressure or by letting the pressure off and then calking. If no leak appears upon again raising the pressure, all is probably well. If the leak continues after repeated calkings, the chances are that there is some yielding.

Old boilers are often tested under water pressure, but a careful inspection, particularly if the boiler be in its setting, is difficult. Then, too, there have been many cases of explosion after such a test, where no evidence of weakness was developed in the test.

Hydraulic testing may be easily done with a hand pump, for the boiler can be filled with a hose, and a pet cock left to let out the entrapped air, so that not much pumping need be done unless the leaks are considerable. A power pump is better, however, for then some air can be left inside the shell, and the strokes of the pump cushioned thereby, while the work of compressing the air is of no account. Where a pump cannot be obtained, the

outlets may be closed, and, after filling the boiler with water completely, a small fire built; the expansion of the water will soon raise the pressure to the desired point, but care should be taken to have a man at the blow-off valve ready to relieve the pressure when it becomes too great, for it will rise fast when once started. In Peabody's Tables of the Properties of Saturated Steam and Other Vapors, at page 35, the increase of the volume of water from 10° Centigrade to 100° C. (the boiling point) is given as $4\frac{3}{10}$ per cent.

In some cases a water pressure of twice the working pressure is put on, but this should not be done unless the factor of safety is at least five.

REVIEW QUESTIONS.

CONSTRUCTION AND DESIGN OF BOILERS.

1. What materials are used in the construction of steam boilers.
2. Name five different kinds of tests which may be used for determining the strength of each material used.
3. When testing materials for tensile strength, what should be the shape of the specimen?
4. What is meant by modulus of elasticity, and how is it obtained?
5. What kind of material is most generally used for shells?
6. What kind of material is most generally used for rivets?
7. What kind of material is in most general use for stay rods?
8. Of what material are tubes generally made?
9. What is meant by tensile strength of a material?
10. What is meant by compressive strength of a material?
11. What is meant by torsional strength of a material?

12. What is shown by the contraction of the area of a specimen when it is tested under tension?

13. What does elongation of a specimen show when tested for tensile strength?

14. What is the effect of heat on the strength of wrought iron and steel?

15. Compare the behavior of a flat plate under pressure with a curved surface.

16. What form of surface will hold the pressure best with the least distortion?

17. Other things being equal, what are the properties of mild steel as used in boiler plates?

19. Name four different kinds of shapes of rivet heads.

20. How should rivet holes be made?

21. Describe the difference between through staying and diagonal staying.

22. What is meant by the efficiency of a riveted joint?

23. Name five different ways in which a single riveted lap joint may fail.

24. How are hydraulic tests on a boiler conducted?

25. Describe the proper method for calking a riveted joint.

The Boiler Shop and Layout of Plates.

IN THE BOILER SHOP.

For the proper construction of steam boilers several special tools are required, usually designed for great strength. A properly equipped boiler shop should have shears and planers for cutting and finishing the edges of steel and iron plates; punches, drills, and boring-mills for making and finishing holes needed in the plates; plate-rolls and flanging machines for bending the plates to the required shapes; hydraulic or steam riveting machines, pneumatic calking and chipping machines, and many kinds of hand tools which will be mentioned later. A machine shop is also needed in connection with the boiler shop proper for doing the machine work required for boiler fittings, furnace fronts, repairing and making tools, etc. A number of large and small cranes and derricks are needed throughout the shop for lifting heavy metal plates and parts of boilers in all stages of construction. A forging shop is always needed for making small parts in iron and steel; and, in addition, boilers, engines, electric generators and motors, pumps, and air compressors for supplying the power needed for operating the shop. In many modern shops the large machine tools are driven by electric motors attached to each machine, so that the electric distribution of power becomes important. The air compressors and pumps are necessary for operating the various kinds of pneumatic and hydraulic machinery, more common probably in boiler shop work than in any other.

In boiler-making large and heavy steel plates must be handled a great deal. Handling these plates is very cumbersome and requires a wide space for every movement. For this reason the boiler shop should be laid out so that the work on the plates can

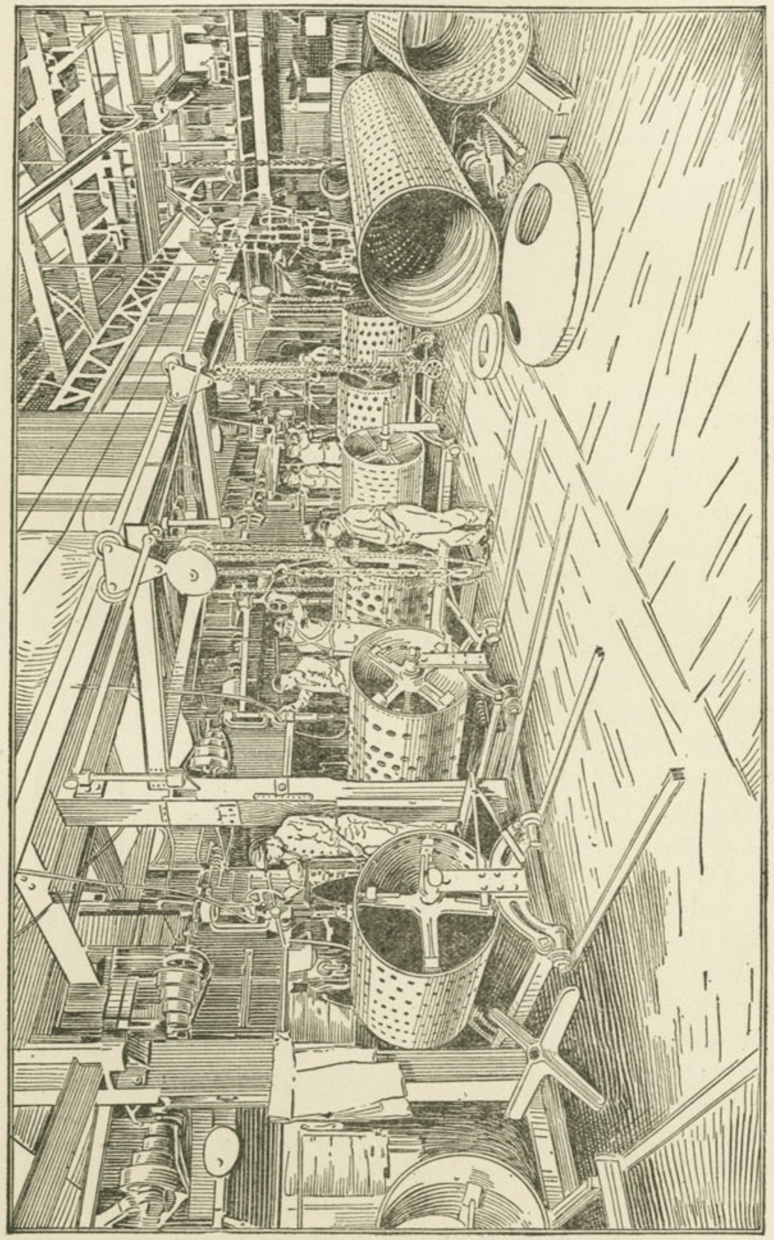


Fig. 1

be done in a progressive manner; the various processes of manufacture to the finished boiler following each other systematically around the shop in the order of the operations to be performed.

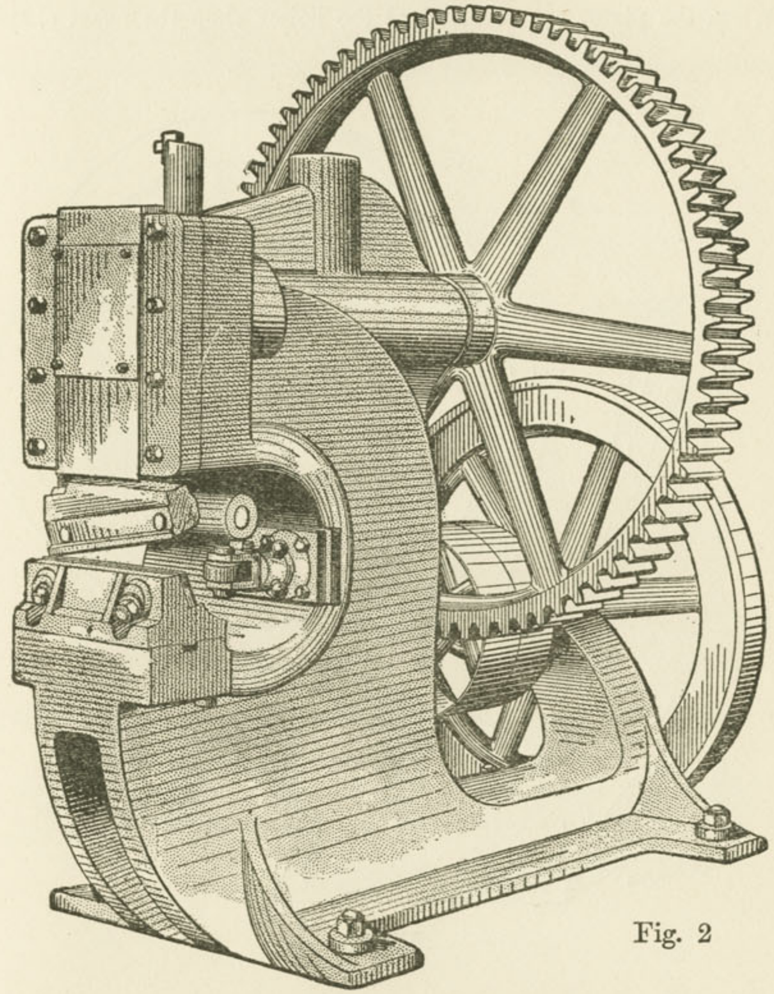


Fig. 2

The heavy machine tools should be arranged in the order they are used. Sufficient space to avoid over-crowding should be provided everywhere, and modern stationary cranes located between the machines should be always available for passing the plates systematically through the various stages of shearing, punching or drilling, planing, rolling, flanging, and riveting.

The plates for the shells can usually be ordered from steel and iron mills of about the sizes needed for ordinary boilers. When the plates are received at the boiler shop the exact shapes

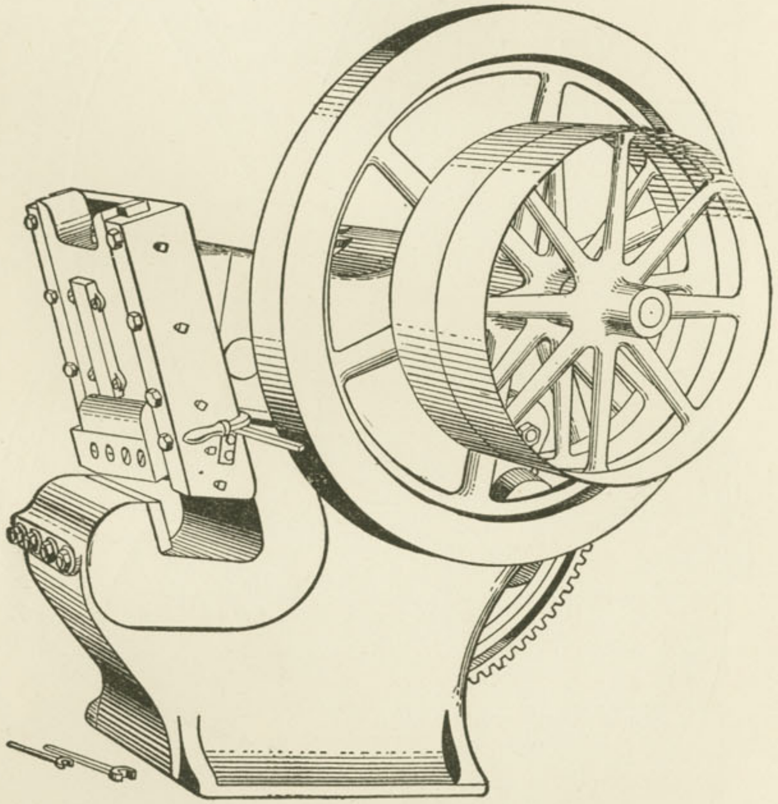


Fig. 3

of the finished plates to make up the boiler are laid out in chalk marks or with a scriber. If large pieces are to be removed, as at the corners, the plates are carried by a crane to a shear, where rough cutting is done. Then the plates are taken to a large metal planer, where they are cut down to exact size, but with a slight

bevel to give some excess of metal at joints, so that the hammering of the seams will be easier in making the boiler "steam-tight."

A view of the interior of a boiler shop is given in Fig. 1. Partly finished boiler shells are to be seen everywhere, and, of course, occupy most of the space in the shop.

Shearing Machines. A simple form of shearing machine or shears is illustrated in Fig. 2. This machine is used for cutting

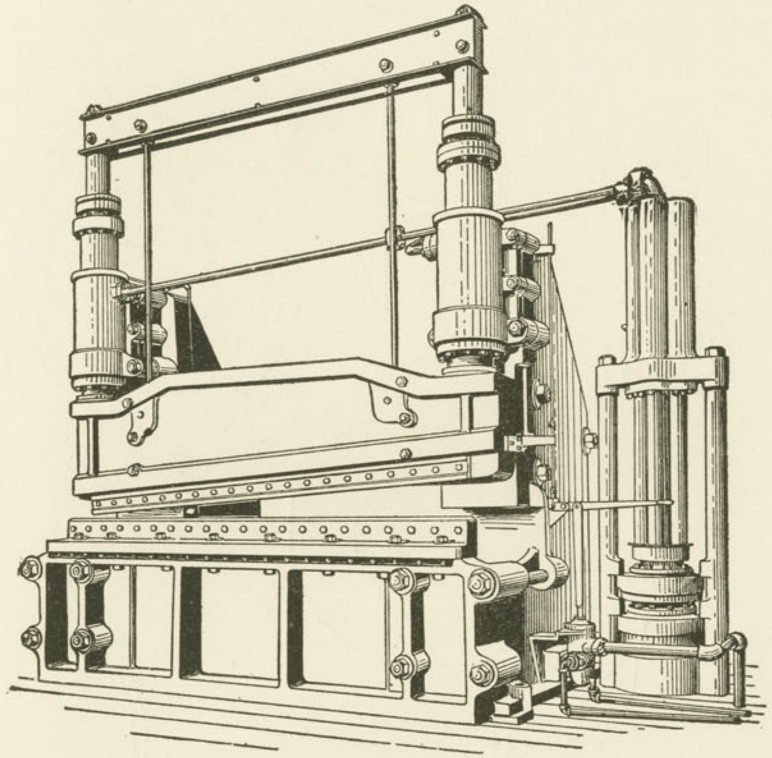


Fig. 4

bars and plates of steel or iron. The power needed for driving the machine is taken from shafting by a belt passing around the heavy band wheel on the main shaft of the machine. The lever on the side of the machine is connected to a clutch, which can be thrown out of gear when the shears are not needed for constant service;

but in most shops the clutch is not thrown out between successive strokes when the cutting is being done. When the lines to be followed in cutting the plate have been plainly marked, the plate is pushed into place on the shearing machine, and on the up stroke

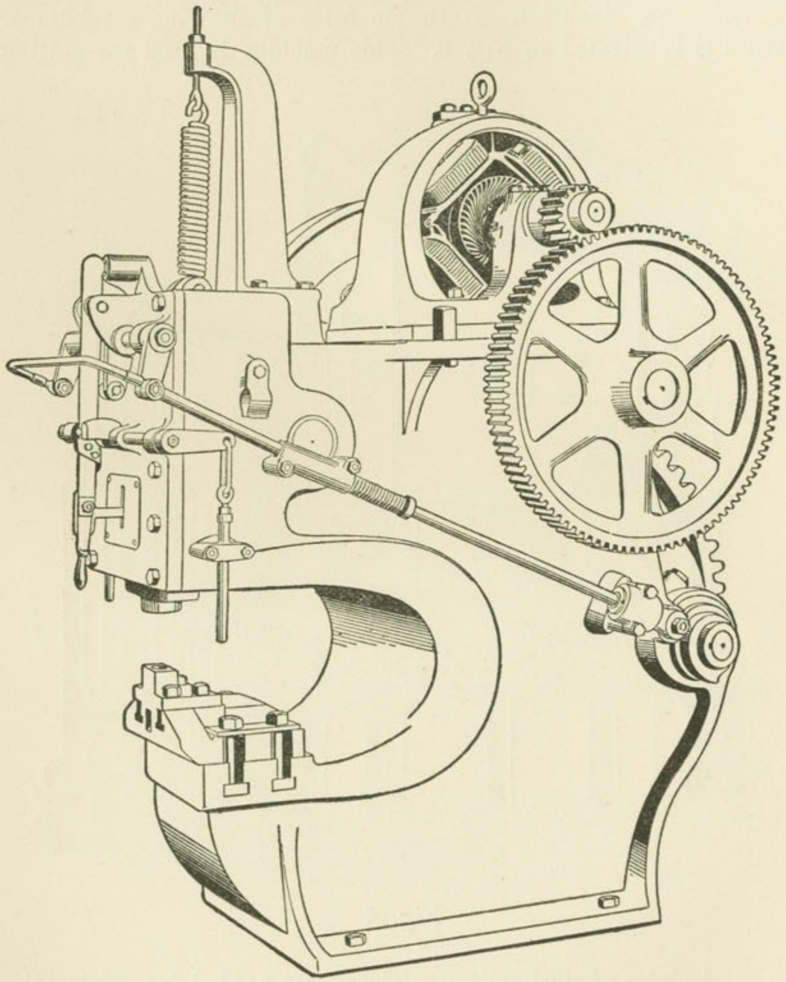


Fig. 5

of the upper cutter the plate is placed so that the edge of the lower cutter is on the line for the cut, and on the down stroke the edges

of the shears pass through the plate. The cut is, however, not very smooth, and some finishing is necessary either with hand tools or with a metal planer.

When large quantities of short pieces are to be cut to the same length, a "stop" plate is usually bolted to the machine behind the cutters. On the up stroke of the cutter, the piece of steel or iron to be cut to the standard size is pushed against the "stop" plate, and at each stroke of the machine the required size is cut off.

Fig. 3 illustrates a belt-driven shearing machine capable of shearing the plate with the required bevel. The head is operated by a cam bearing against a roller in a lever, which in turn bears upon a steel block in the head, which is started and stopped by a

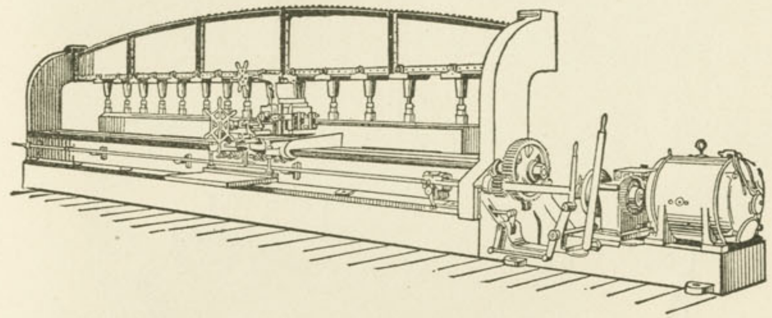


Fig. 6

hand lever or treadle connected with a clutch on the cam shaft. When stopped the head is always at the upper end of the stroke.

Fig. 4 shows a multiple power hydraulic plate shear. The essential features consist of the direct application of the power to the knife without intervention of gears, eccentrics, clutches, levers, or wedges, thus securing the highest possible efficiency in operation; the multiple power compound intensifier, which insures absolutely equal and simultaneous action of the two rams which operate the cutting knife, regardless of the position of the point of resistance to the knife, and which also provides for the most economical operation of the tool by permitting the application of varying powers in shearing different thicknesses of plate; the arrangement of the upper knife holder, guides and bearings, which permits either end of the upper knife holder to make a complete stroke,

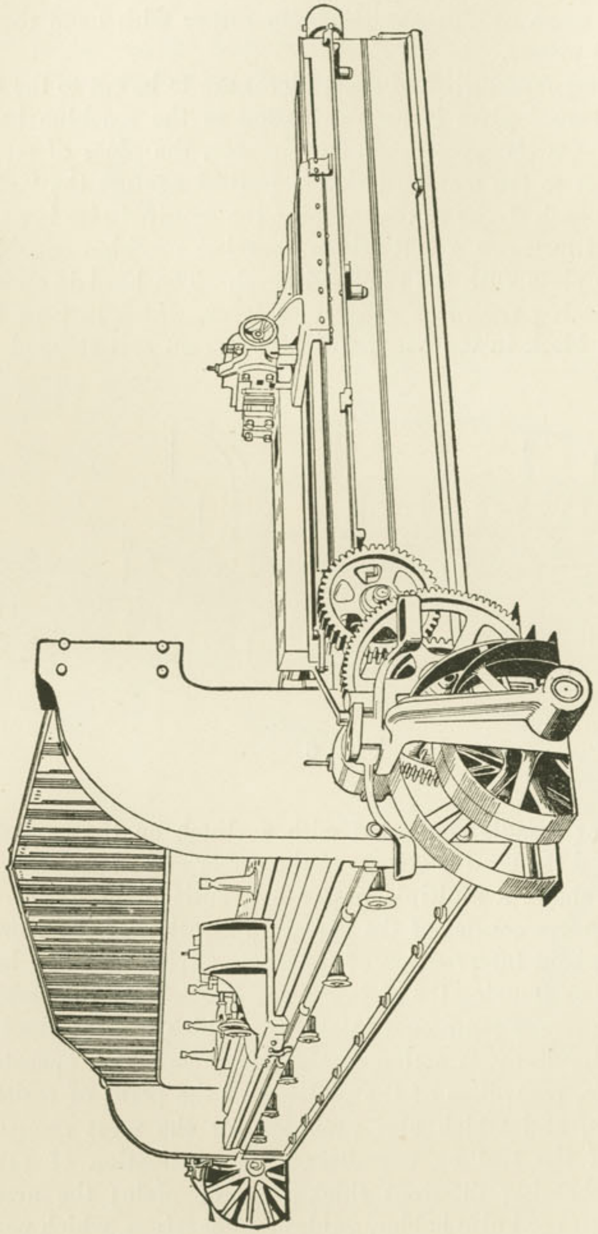


Fig. 7

while the opposite end remains stationary should such a movement occur due to an accident; the arrangement of the operating valve, so that it is automatically closed just as the upper knife holder reaches either end of its stroke, thus relieving the shocks which

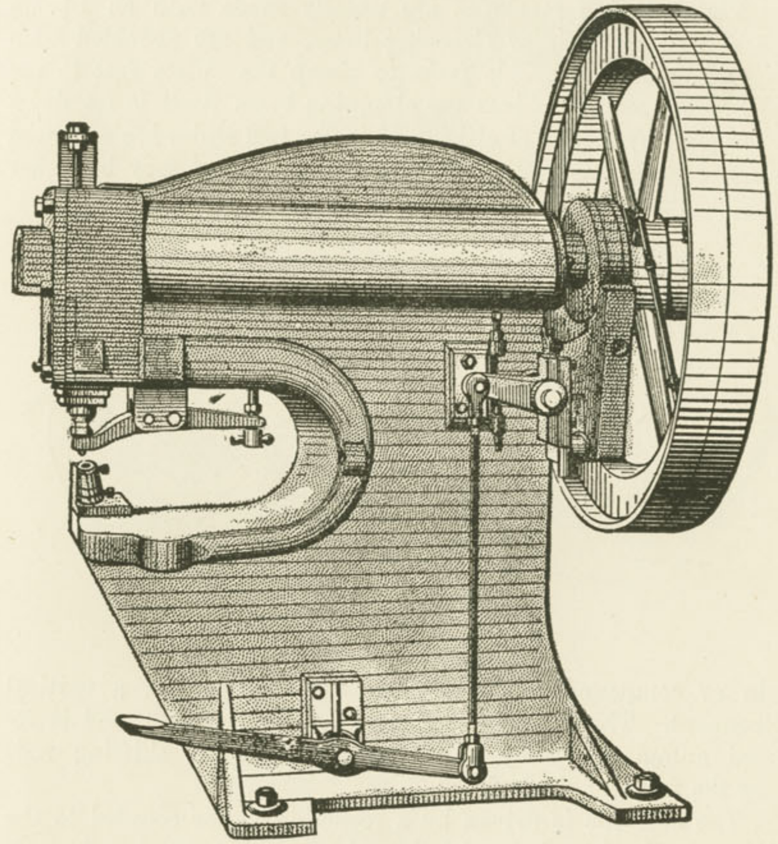


Fig. 8

would otherwise result. The knives are made of the best grade shear steel and each has four cutting edges.

The design provides a tool entirely self-contained as far as working strains are concerned, and of absolute rigidity. It combines the utmost simplicity with the highest efficiency, the frictional losses having been reduced to a minimum.

Fig. 5 shows a shearing machine driven by an electric motor.

Plate Planing Machines. The plate planing machine shown in Fig. 6 is intended for planing boiler plates and shop plates. The table of the machine is large enough to take the largest plates that are likely to be worked in the boiler shop.

Plate planing machines are usually made with an I-beam or a riveted plate-girder clamping beam, and are provided with trolley jacks or removable jacks to clamp the plate fast to the table. For small machines the clamping beam itself is set down on the plate by screws at either end. The tool slides are arranged with two tools, one cutting in each direction, and may be either

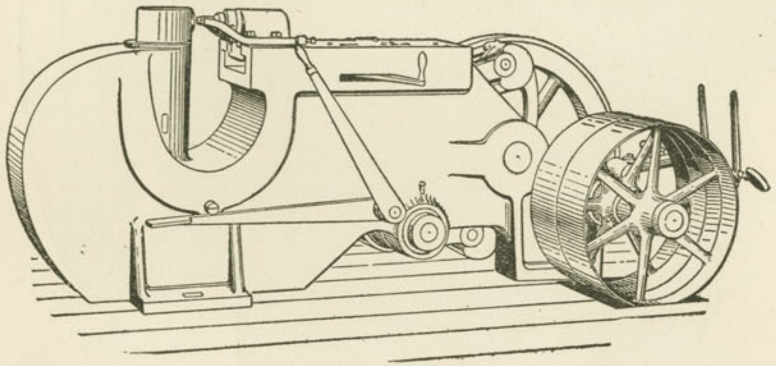


Fig. 9

plain or compound. The compound tool slide has a vertical adjustment. The carriage is driven by heavy screws, and is reversed automatically by adjustable dogs on the shifting rods along the front of the bed.

The machine is driven by a reversing motor coupled to the driving mechanism by a friction clutch. A special automatic controller is used for starting, stopping, and reversing the motor. The operator controls the machine either from the carriage or the motor.

For planing two adjoining edges of a plate duplex planing machines, which have end planing attachments, are used. Fig. 7 illustrates a machine of this type.

Punching Machines. Punching machines or punchers are used for making small holes in plates, usually not over an inch in

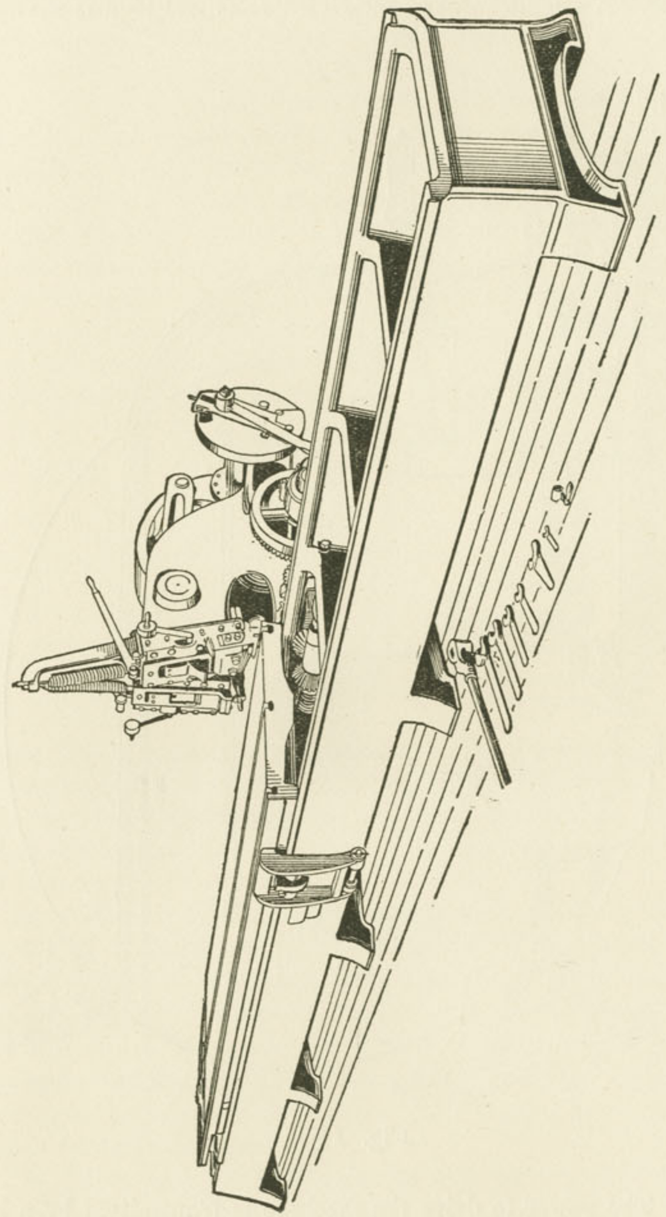


Fig. 10

diameter. These machines in many details are much like shearing machines. A simple form of punch for steel and iron is shown in

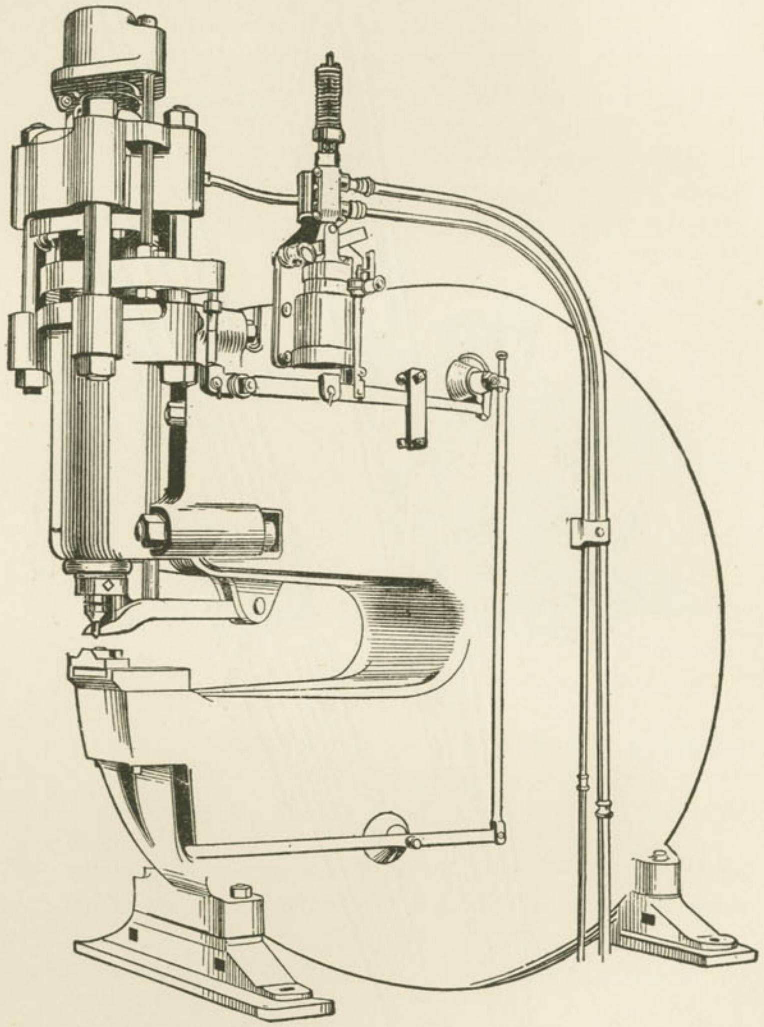


Fig. 11

Fig. 8. The power to drive the machine is transmitted by a belt from shafting to the band wheel, as in the case of simple shears.

The main shaft A of the machine, together with the band wheel, are always in motion when the shafting in the shop is running. The punch itself is moved, however, only when a hole is to be cut. The mechanism moving the punch is connected to a cam B on the main shaft, and when this cam is thrown into gear by the operator moving the hand lever at the side of the machine the punch descends and pierces metal of considerable thickness placed beneath it. When the cam is disengaged the punch is always left in its highest position, so that the plates can readily be adjusted in the space beneath it. The center of the punch can be thus made to strike accurately the hole to be punched. The power required for the blow to penetrate thick metal is much greater than could be transmitted by the small belt that is used on such machines; but the energy stored in the heavy band wheel when the machine is

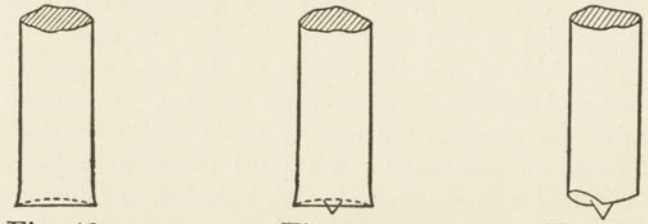


Fig. 12 Fig. 13 Fig. 14

running idle is turned to good account when the blow is struck. Then again, when the punch is withdrawn from the hole it has made, the clutch connecting the punching mechanism with the shaft is disengaged; but the band wheel continues to revolve in order to store up energy for the next blow.

Fig. 9 shows a horizontal punching machine made by Bement, Miles & Co., Philadelphia. The head is driven by a lever, and is stopped and started by a hand lever engaging a gag of hardened steel. The punch is brought forward against the work for accurate punching to lines by a second lever projecting from the side of the frame under the sliding head. Dies are held in a steel stick which passes through the frame and allows small flanged pieces, such as heads, to be easily punched.

Fig. 10 shows a punching machine with an automatic spacing table. It is designed to punch holes at the rate of 60 to 80 strokes per minute. The table will hold sheets of any width and will space automatically, and also has a quick return. The table can be arranged to space accurately for holes of any desired pitch up to 3 inches. Inside and outside sheets may be punched, so that when rolled and fitted together the holes will exactly correspond.

Fig. 11 illustrates a hydraulic punch. The principal feature of this machine is an automatic stripper, which descends upon the plate, remains there until the hole is punched and the punch withdrawn from the plate, then rises $\frac{1}{4}$ inch above the end of the punch, leaving the latter to engage in the next center-punch mark.

The punches and dies used for making holes in boiler plates are usually of about the same general pattern. They are always cylindrical, and the head on the cutting face is made a little larger in diameter than the rest of the cylinder. This enlarged cutting face is shown in some of the figures that follow. A punch with a plain edge or cutting face is illustrated in Fig. 12. A form of punch with a center-point on the end is represented in Fig. 13. This center-point is very useful for helping the operator of the punching machine to find the centers of the holes marked on the plates, and makes accurate work easily possible. These two kinds of "heads" for punches are usually made with a face which is slightly concaved (hollowed out toward the center) to make a cleaner cut and a smoother hole. A spiral face on a punch is shown in Fig. 14. The action of such a punch in cutting metal is supposed to be less liable to injure the surface of the plates near the holes than the other forms. When holes larger than an inch in diameter are to be punched this spiral form is always used.

Making holes in thick metal plates with a punch is generally considered a rough and unsatisfactory method, so that drilling has superseded punching very largely, especially for boilers intended for high pressures. The punch in passing through steel or iron plates which are always of a slightly fibrous or stringy nature has a tendency to open seams in the metal around the holes. When the holes are being made the metal is pushed or broken out by the punch without being cut. Wrought iron is more fibrous than steel, so that this metal is injured more from this cause than steel. This fibrous or stringy quality of wrought iron can be well observed by breaking a small rod by alternately bending the ends together and straightening the rod out several times. The fracture will be seen to be very rough and fibrous. On the other hand, when very hard and slightly brittle steel plates are punched, small cracks

are often formed around the holes, which reduce the strength of the plate very much in the vicinity of the holes. Thin plates of soft and ductile (yielding) metal are least injured by punching.

In soft and ductile boiler plates the injury to the metal as the result of punching holes is usually confined to a ring around the hole about as wide as one-third of the thickness of the plate. For

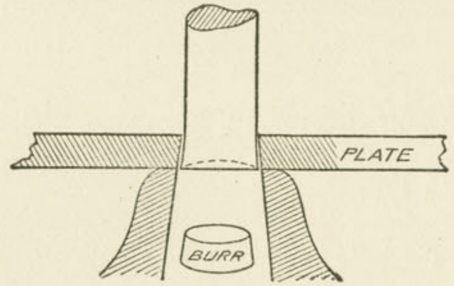


Fig. 15

this reason many boiler makers punch all rivet holes one-eighth of an inch too small and ream them to the required size for the rivets.

When the ends of the punch and die are not well designed there is often much greater injury to the metal from punching than has been mentioned above.

The loss of strength in a plate due to punching is greatly

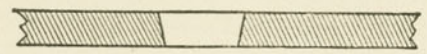


Fig. 16

affected by the form of the shearing edge of the punch and the size of the hole in the die-block. If the punch fits the hole in the die-block exactly without any clearance, the loss of strength will be excessive; but there are also very bad results when there is excessive clearance, that is, when the punch is considerably smaller than the die. The action of the punch and the effects on the plate when the clearance is much too large are well shown in Fig. 15.

The amount that the diameter of the die should exceed that of the punch for the best results depends on the thickness and nature of the metal. A rough-and-ready rule commonly accepted is that the diameter of the die should be 1.1 times the required diameter

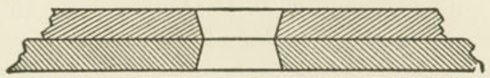


Fig. 17

for the usual size of rivets and boiler plates. Thus for rivets $\frac{3}{4}$ inch diameter and $\frac{1}{2}$ inch plate the diameter of the die should be $\frac{3}{4}$ multiplied by 1.1, or about $\frac{13}{16}$ inch.

Fig. 15 also shows that the effect of the clearance between the punch and the die is to produce a hole with slanting instead of

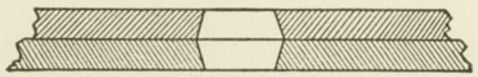


Fig. 18

straight sides. In other words, the hole is conical, very much like the illustration in Fig. 16.

Punch plates should be placed together at a joint which is to be riveted, so that the large ends of the holes are on the outside, as in Fig. 17. When hot rivets are hammered and squeezed in

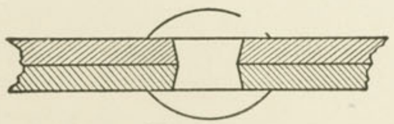


Fig. 19

making the joint, it is much more likely that the metal of the rivets will fill up these cup-shaped holes than when the holes are placed the other way, as in Fig. 18. A tight riveted joint is only assured when the holes are completely filled with the metal of the rivet, otherwise the rivets are likely to be loose. Fig. 19 shows a rivet which properly fills the holes in punched plates.

In general, we may say that a good soft and ductile boiler plate is not seriously injured by punching if it is done carefully and every precaution is taken to remove the bad effects. Wrought iron plates are usually more ductile than the steel plates, and are

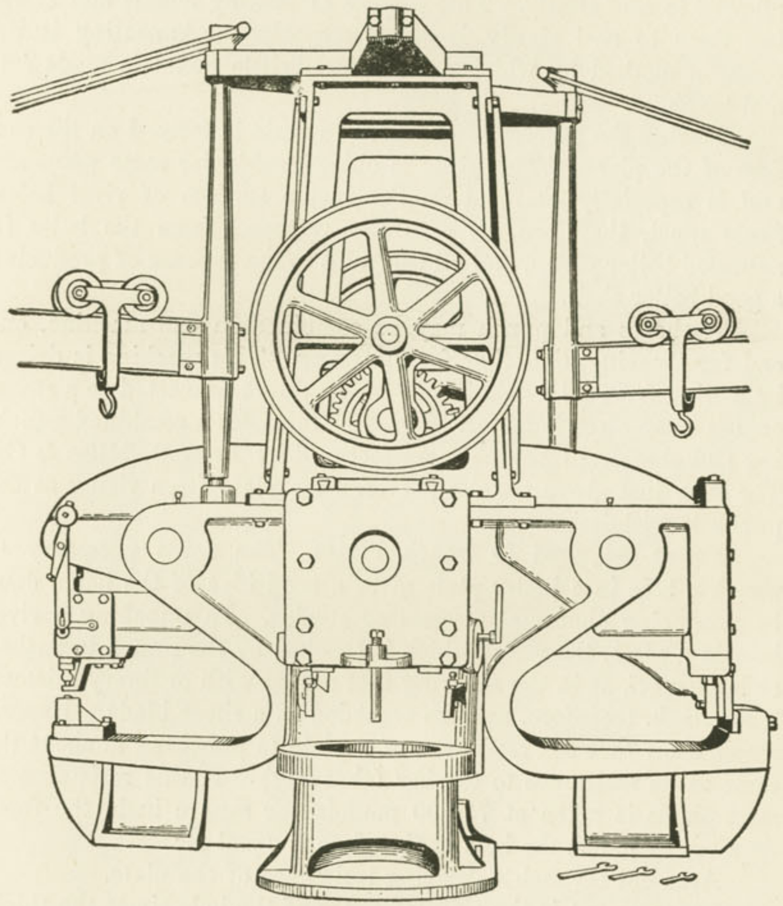


Fig. 20

intended for comparatively low steam pressures. The greatest possible precaution to secure the highest strength of the plates is, therefore, not so essential. For these reasons the holes in wrought iron plates are commonly punched and those in steel plates are usually drilled.

The practice of punching the holes in boiler plates a little small and reaming out to the required size has already been mentioned. After punching, many boiler makers put the plates into a furnace, and when heated to red heat they are taken out and allowed to cool slowly. This process of heating metals and allowing them to cool slowly is called *annealing*. Annealing is the common method by which a hard and brittle metal is made soft and tough.

During the process of annealing a scale is formed on the surface of the plates. This scale is objectionable for some purposes, and is especially harmful on the inside surface of rivet holes. Scale must, therefore, be carefully removed from the holes in annealed boiler plates, and all this adds to the expense of producing a good boiler shell.

A shears and punch may be combined in one machine, one end for shearing, the other for punching. This machine is driven by belting from a line shaft, or may be direct connected to a steam engine or an electric motor. Fig. 20 illustrates a combined punching and shearing machine manufactured by Bement, Miles & Co. The fork just above the die prevents the plate from rising as the punch is withdrawn.

Power Required to Punch Plates. The force necessary to punch a hole in a boiler plate gives a good idea of the harm done by producing abnormal stresses or strains. In punching a rivet hole in a plate, the metal which is touched by the punch is pushed or broken off, as in the shearing that occurs with ordinary scissors. The punch, therefore, may be regarded as a shear blade. Experiments show that the resistance of a plate to punching is about the same as its resistance to tearing (shearing). If this resistance of steel plates is taken at 75,000 pounds per square inch, the force required to punch the hole in the plate is equal to:

Area cut through × shearing resistance of the plate.

The area cut is the circumference of the hole times the thickness of the plate. Let d be the diameter of the hole and t the thickness of the plate; then $3.1416 \times d$ is the circumference of the hole and the area cut is $3.1416 \times d \times t$.*

* The area of the *hole* is $3.1416 \times \frac{d^2}{4}$ (the area of a circle); but in this case the cutting area is in the shape of a circular ring, of which the circumference of the hole is one dimension and the thickness is the other.

If a $\frac{7}{8}$-inch hole is to be cut in a $\frac{3}{4}$-inch plate, the area cut through is:

$$3.1416 \times \tfrac{7}{8} \times \tfrac{3}{4} = 2.06 \text{ square inches.}$$

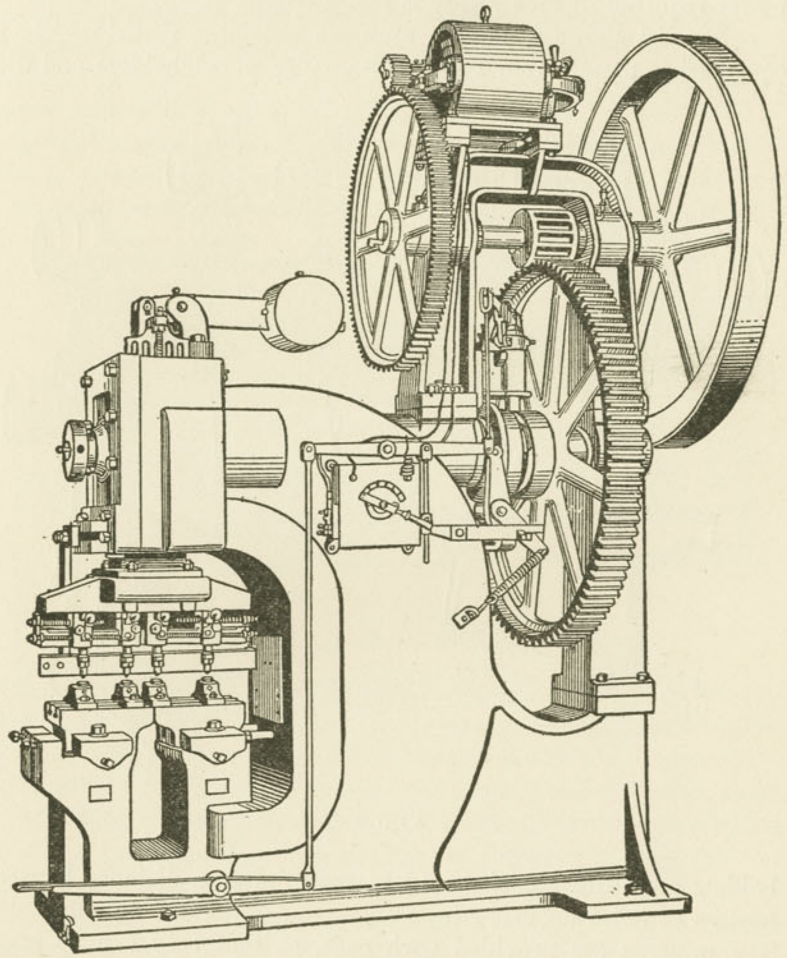


Fig. 21

The force of the blow is:

Shearing resistance × area cut through, or

$$75{,}000 \times 2.06 = \text{nearly } 155{,}000 \text{ pounds.}$$

If the force needed to punch one hole is 155,000 pounds, a correspondingly greater force is required to punch several holes at the same time, as in some of our multiple punching machines with several punches operated at once on the same plate. The power required in such a case is really enormous.

Fig. 21 shows a modern multiple punching machine. It is equipped to punch from 1 to 4 holes. The punch-holders and die-

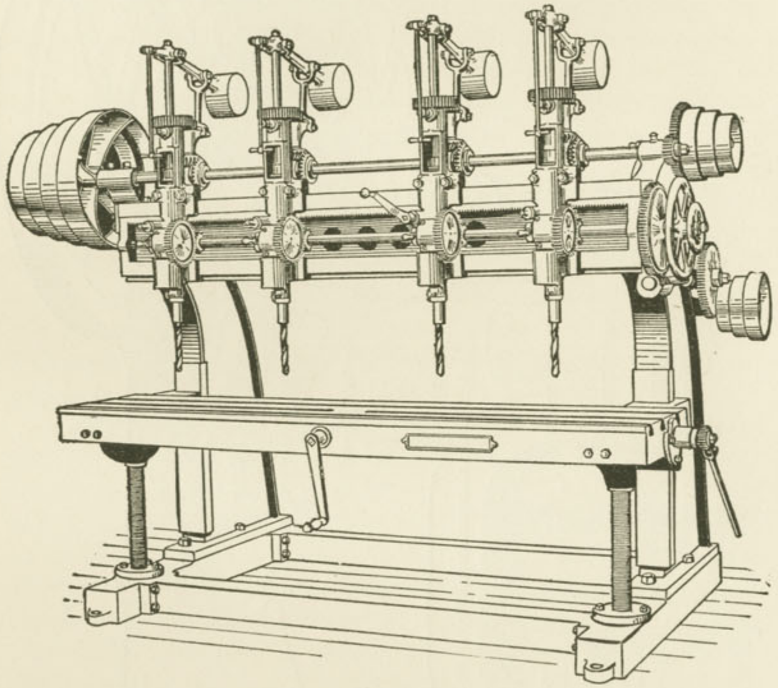


Fig. 22

holders are adjustable from $1\frac{3}{8}$ inches minimum distance between centers of holes up to 24 inches between centers of outside holes. The punches are provided with gags, so that they can be made inoperative and do not have to be taken off in changing the number of holes to be punched. The machine is driven by an electric motor which can be attached in any desired position.

Drilling. In modern boiler shop work the holes in plates are usually drilled and not punched. Punching is cheaper than drilling, but, on the other hand, it is less accurate. It is obvious that

when rivet holes are drilled the plate is subjected to much less stress or strain, even if twenty are drilled at once, as in some of our modern multiple drills, than when one hole is made with a punch.

Fig. 22 is an illustration of a modern multiple drill.

For all marine work the rivet holes must be drilled, and the specifications of the U. S. Navy absolutely demand it. Drilling permits more accurate riveting than punching, as the holes are spaced more readily, and, therefore, usually more correctly. There is no difficulty about drilling plates after they have been bent into shape. When the holes in plates for a boiler shell are to be drilled, a few holes are made in each plate before it is bent, and when the

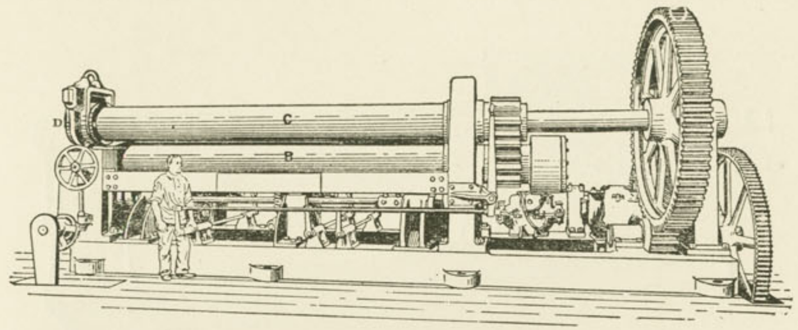


Fig. 23

plate has been rolled to the proper shape, temporary bolts are put through these holes and the other holes are drilled in the plates just as they are to be joined. This method makes accuracy certain. After drilling the holes, however, the plates must be taken apart by removing the bolts, so that the sharp edge or burr of the drilled hole can be removed. This drilling of plates "in position" is usually done with portable drills.

Drilling of boiler shells is sometimes done with a special drilling machine so arranged that the boiler shell can be turned on the cradle or bed so as to bring any portions of the surface to the drill.

Plate-bending. After the plates for the shell of the boiler have been cut to size and the small holes have been cut out, they are carried to a plate-bending machine, where they are bent to a cylindrical shape by being passed through rolls much like those used for rolling bar iron in rolling mills.

The makers of plate-bending machines have various designs, differing only in details and dimensions. A common and simple form of these machines is shown in Fig. 23. This machine consists of three rolls arranged in "pyramid" form. There are two lower rolls B and one upper roll C. The lower rolls are connected to each other by powerful gearing.

When a boiler plate is to be rolled from a flat to a curved shape it is placed on the lower rolls, and the upper roll is lowered till it grips the plate. The rolls are then started and the plate is run through till the rolls have passed nearly to the other edge of the plate; then, before the plate falls from the machine, the rolls

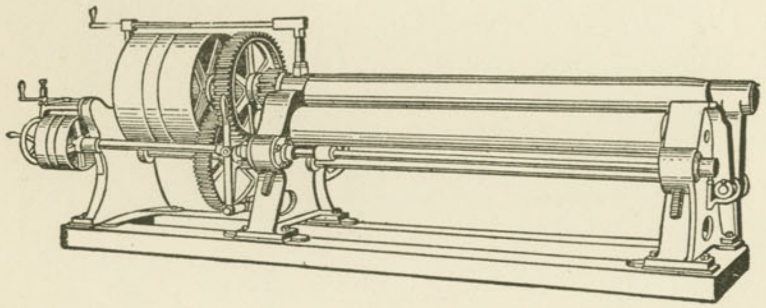


Fig. 24

are quickly stopped and the top roll is screwed down to increase the curvature on the next passage through the rolls. The machine is then reversed and the plate is run through the rolls in the other direction. After each passage through the rolls, the upper roll is lowered a little and the plate is carried back and forth through the rolls till it has the required curvature.

Except when the plate has been rolled into the form of a complete circular ring or near that shape, the machine will discharge the plate by the movement given by the rolls. When, however, a circular ring has been made, as is so common for boiler shells and furnace flues, it cannot be removed without taking off the end of the machine and raising the upper roll to remove the pressure. To make this operation possible, one bearing of the upper roll (shown on the left in Fig. 23) has a hinge in the support D, which

support may be thrown back, leaving the roll free for the removal of the plate.

There is also another common type of plate-bending machine often found in boiler shops. In this machine, Fig. 24, there are three rolls as in the machine already described, but the two smaller rolls are in a vertical instead of a horizontal plane. In this machine these two rolls are called the "pinching" rolls. The larger, or bending roll, is placed in front of the two smaller rolls. In this arrangement the upper and lower "pinching" rolls are geared together, but revolved in the same direction and at the same speed. Also, the height of the bending roll will determine the amount of curvature given to the plate.

In either of these machines the bending roll is usually run

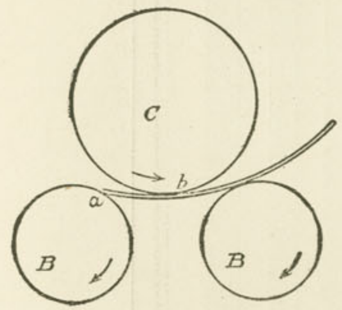


Fig. 25

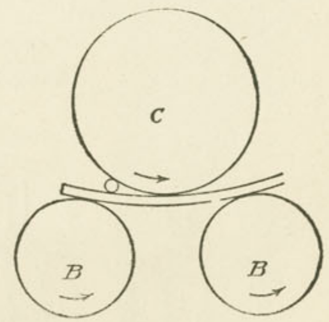


Fig. 26

idly from the friction of the plate; that is, without gearing; and the plate is run through merely by the motion of the other two rolls. When, however, very heavy plates are to be bent, the bending roll must also be driven by power from the shaft, usually with additional gear wheels. In modern plate-bending machines the bending roll is raised and lowered by gears or motors connected to the screws, which, as shown in Fig. 23, are moved by hand. Instead of the hinged support for the upper roll shown in Fig. 23, some plate-bending machines are made so that the removable bearing is in a pivoted "cheek."

In the use of these bending machines there is always difficulty in bending the *ends* of the plates. The bending effect of the rolls cannot be made to extend to the extreme edges on account of the end of the plate falling between the rolls in such a position that the plate is merely rolled along without being bent. This position of the plate with respect to the rolls is illustrated in Fig. 25. When the plate is in this position there will be a straight part of the plate between *a* and *b*. The length of this "straight part" can be made comparatively small by making the lower rolls B smaller and at the same time bringing them closer. If, however, the lower rolls are not close enough to make the length of this

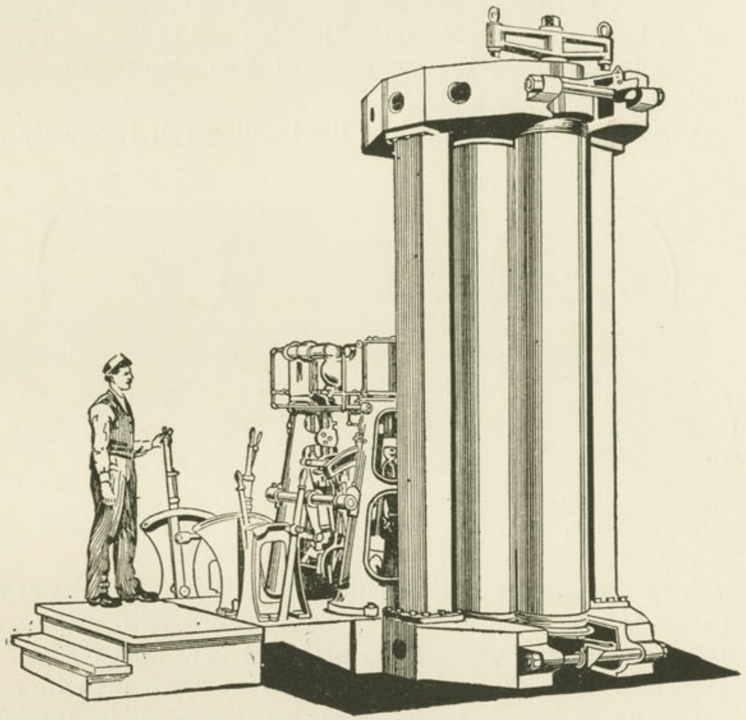


Fig. 27

straight portion negligible, a narrow piece of wood, or, still better, a bar of curved iron with a nearly semi-circular section is placed on this part of the plate as it goes through the rolls. In this way a suitable pressure is brought to bear upon the end of the plate, giving it the required curved shape. A curved iron bar is shown in position between the upper roll and the plate in Fig. 26.

Vertical bending rolls like Fig. 27 are very useful for long

plates and for arcs of large radius. If the floor of the shop around such a bending machine is covered with sheet iron, a good support is provided for handling large plates without the assistance of cranes. With horizontal rolls, overhead cranes are always needed to support very large and heavy plates passing through the rolls. Vertical rolls have also the important advantage of giving a truer finish to the ends of the bent plates. When circular rings are

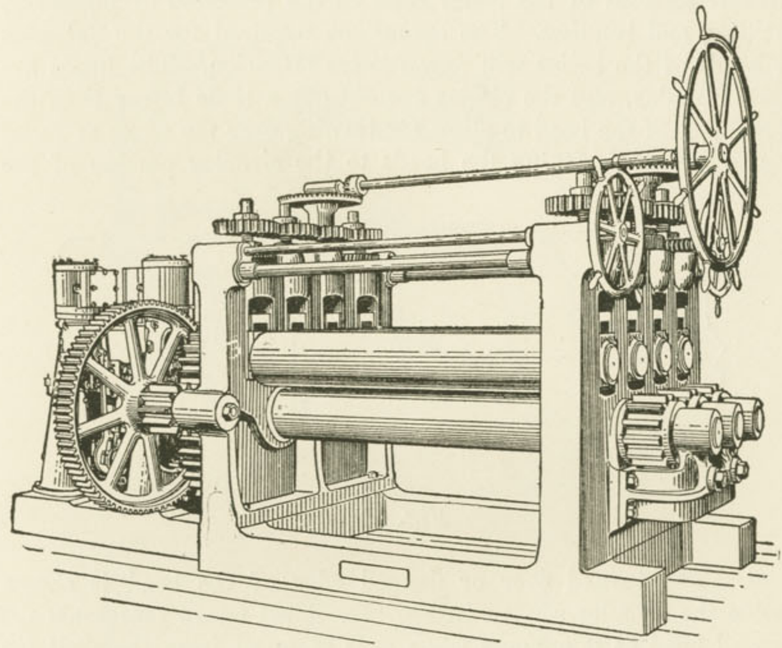


Fig. 28

rolled, the front roll is moved up vertically through the top of the machine to permit the removal of the plate.

The amount of curvature to be given the plates is determined by trial with a template which has been cut to fit an arc of a circle corresponding to the diameter of the boiler.

Straightening Rolls. Plate-straightening machines are similar to bending machines, except that they have more rolls. A good example of this machine is illustrated in Fig. 28. It has four rolls in a row at the top and three below. The upper rolls can be raised and lowered together, and usually each roll has attached to it a graduated scale for accurate adjustment. Steel or iron plates can be made accurate plane surfaces (that is, absolutely flat sheets) by passing them several times through this machine.

The lower rolls are stationary, and are connected with each other by gearing, and with the line shaft by belting, or there is an independent drive from an electric motor.

Boiler Heads. We have been discussing almost entirely the circular sections of the boiler shell in the processes of punching, drilling, and bending. The operations required for the flat ends or heads of the boiler will now receive attention. The heads are made circular, and the circles are cut out a little larger than the actual size of the head to allow for turning over the edges or flanging to permit fastening the heads to the circular portion of the shell.

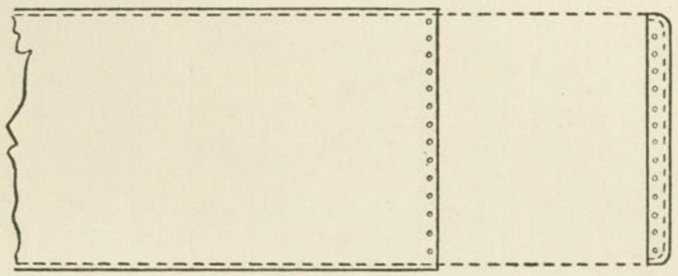


Fig. 29

The turned over or flanged edge of the head is shown beside the circular section in Fig. 29. This figure represents the flanged head as it appears when it is removed from the shell for cutting off the rough burrs on the rivet holes after drilling.

Flanging. Making a flanged edge on a boiler plate is the most severe test to which it is subjected before the boiler leaves the shop. For this reason great care must be taken that the plates do not develop small cracks which will later prove disastrous. To save the plate from injury the turn of the edge of the plate in flanging should be made with a well rounded corner. A very sharp corner is liable to cause the plate to break off at the bend. At present in the best shops flanging is done almost entirely with machines.

In all flanging processes the plates are heated in a furnace to a red heat before any edges are turned over. Also after the plates

have been flanged they are again heated in the furnace for the purpose of removing, by annealing, the local stresses caused at the bends. In the annealing process the whole plate is usually heated to a dull red heat and then allowed to cool slowly.

Flanging machines are really presses, similar to the one illustrated in Fig. 30. This machine is used mostly for flanging circular head plates, furnace flues, etc. The important working parts of this machine are shown in Fig. 31, showing diagrammatically the machine originally called by boiler makers Tweddell's press.

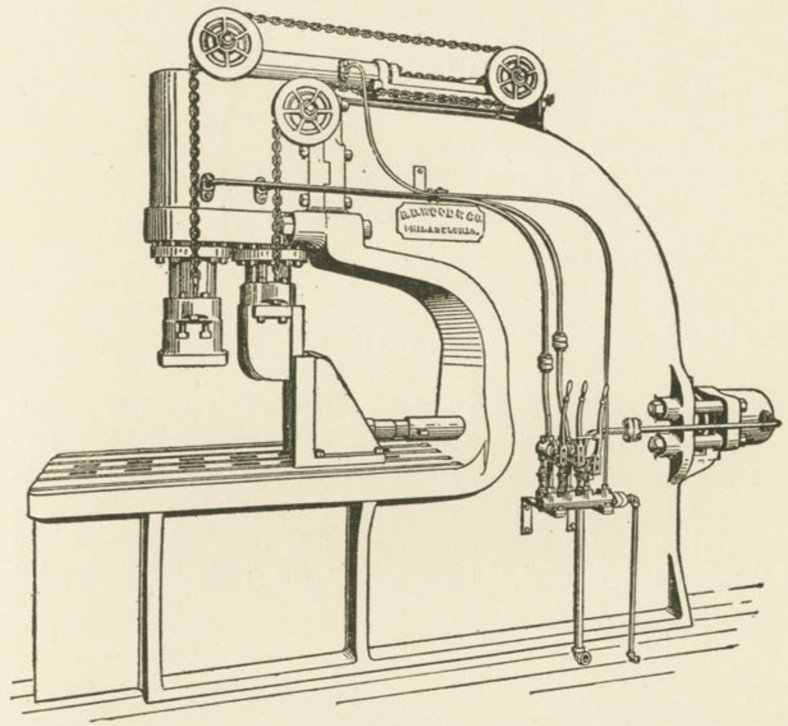


Fig. 30

The heavy framing of the machine contains two vertical cylinders with vertical piston-rods A and B. A die D on the end of the rod A is used for holding the plate P, while the die E on the rod B does the flanging or turning over of the plate around the block F. The ram C has a horizontal motion. When it is not operated its face is not in sight, in order to leave the space clear for the operation of the die E. The ram C is used for finishing or squaring up the flanged portion of the plate. The block F is usually circular because most parts to be flanged are of this shape.

Large flanging machines can be used for flanging furnace

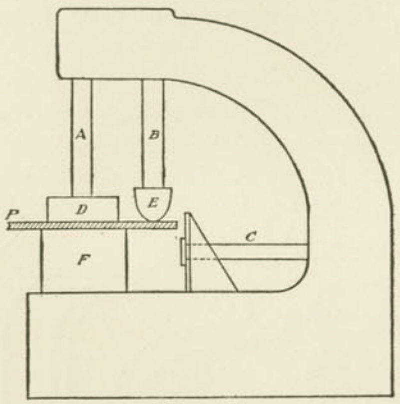


Fig. 31

flues in one operation, and it is done with the best possible results.

Welded Joints. Where joints in a boiler are subjected to great pressure on the *outside* rather than from the inside, as in furnace flues of internally-fired boilers, welded joints are desirable. When riveted joints are subjected to the most intense heat of the furnace, as over the grate, they are liable to get too hot

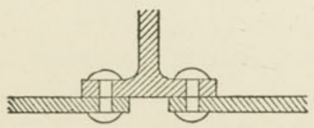


Fig. 32

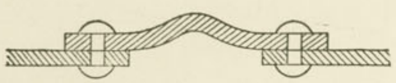


Fig. 33

and the heads of the rivets may be burned off. For this reason riveted joints should be avoided where the heat is great, and welded joints used instead. Methods of joining sections of furnace flues are illustrated in Figs. 32 and 33. These designs are particularly bad because the heads of the rivets are exposed to the intense heat of the fire. They are likely to be burned and consequently

weakened, just as rivets may be ruined by excessive heating to white heat before driving.

By the use of *welded* joints we avoid the deposits that are sure to accumulate on the inside of a boiler around rivet heads and rivet joints; in addition there is no corrosion or rusting from leakage through imperfect joints due to loose rivets and careless calking.

A perfectly welded joint is much stronger than the best riveted joint, and nearly as strong as the solid plate before the holes were cut. The strength of a joint, and, therefore, of the whole boiler, is determined by its weakest part. Welded joints when carelessly made may look very good and still be very poor for strength. The soundness of welded joints is, therefore, actually very uncertain, depending largely on the skill and care of the workman. A

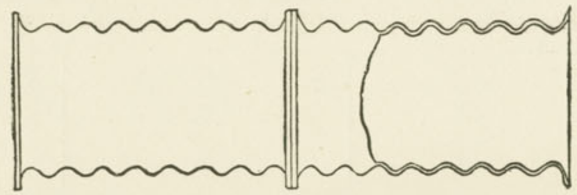


Fig. 34

weld must always be considered about 5 per cent weaker than the solid plate, and often apparently good joints are from 50 to 60 per cent weaker. As a rough-and-ready rule we may say that the average strength of welded joints is about 75 per cent of the strength of the solid plate.

For all kinds of construction where a broken joint would be disastrous to life and property, as in the joints of a steam boiler *shell,* welds should not be allowed, unless the steam pressure is so low that such joints would be absolutely safe.

The steam drums of marine water-tube boilers often have welded joints if the drums are small compared with the size of the complete boiler. For high pressures in modern boilers, however, it seems as if riveted joints should be preferred.

Corrugated flues, Fig. 34, are always made with welded joints and are comparatively safe, because the steam pressure is on the outside of the flue. All such tubes are much stronger to resist pressure from the outside than from the inside; and, on the other hand, if a rupture did occur the damage would not be so serious as a failure in the shell, as the water from the boiler would pour into the furnace flue, put out the fire, and take more of the nature of a flood than a boiler explosion. The damage would be internal rather than external.

A welded joint for steel boiler plates is made most satisfactorily when the two edges to be welded are upset when at a red heat to about double the thickness of the original plate. After the upsetting, the two edges are heated at the same time to a "welding heat" in a furnace, and then the joint is made by quickly hammering down the edges on each other till the joint has the thickness of the plate.

Riveted Joints. The most satisfactory joints for all kinds

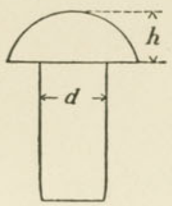


Fig. 35

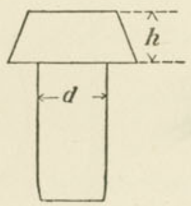


Fig. 36

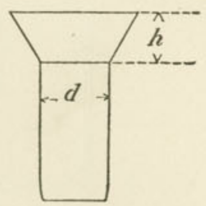


Fig. 37

of boiler-making are made by fastening the ends of plates together with iron or steel rivets. These rivets are made from round bars of wrought iron or mild steel of a special quality which is both tough and ductile. Pieces of the required length to make a rivet (considerably longer than the finished rivet to allow for making the heads) are cut from the bar. These pieces are heated to a red heat in a furnace, and are then put into dies, where one end is pressed into the form of a rivet *head,* and the other end, called the *shank,* is slightly tapered for about half its length, so that it will easily fit the holes in the boiler plates. Rivet heads of the most common forms are illustrated in the accompanying figures. Fig. 35 shows a pan-shape rivet, Fig. 36 a cup-shape, and Fig. 37 a countersunk rivet. The rivet head, which is made in the die before driving, is usually pan-shaped for hand riveting and cup-shaped for machine riveting.

Sometimes it is necessary to make the head of a rivet flush

with the plates. This occurs most often where steam domes and boiler fittings are to be attached to the shell over a riveted joint. Instead of shaping the part to be added to fit cup-shape or pan-shape rivets the joining surface is made regular and the rivet head is depressed at the points where the surfaces intersect. For such depressed rivets, called countersunk, a tapering hole is cut out of the plate where the head is to be located. This tapering or conical part of a rivet hole is called the countersink. If there is no interference with the rivet head on the other side of such a joint, that head should be made cup-shape, pan-shape, or conical rather than countersunk. It is recognized by engineers that the greatest strength of a rivet comes from the *friction* of the flat surface of the

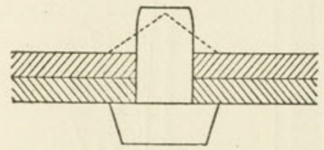


Fig. 38

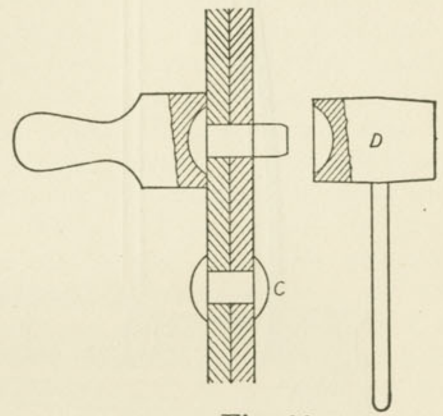


Fig. 39

head next to the plate. This friction in a well-made joint may be greater than the crushing or shearing strength. With a countersunk rivet it is obvious that this frictional resistance is not applied to advantage; and, on the other hand, when forces come on such a rivet in a direction normal to the surface of the plate, countersunk rivets have been observed to slip through the plates. The countersunk head is made by pressing with a riveting machine or hammering by hand the shank of the rivet into the countersink in the plate.

The largest diameter d of the shank of a rivet is usually $\frac{1}{16}$ inch smaller than the holes in the plates; and the largest diameter of the rivet head is twice the diameter of the shank, that is, two times d. The height h of the head is made $\frac{2}{3}\,d$. Rivets are always made long enough to have a considerable portion extend beyond

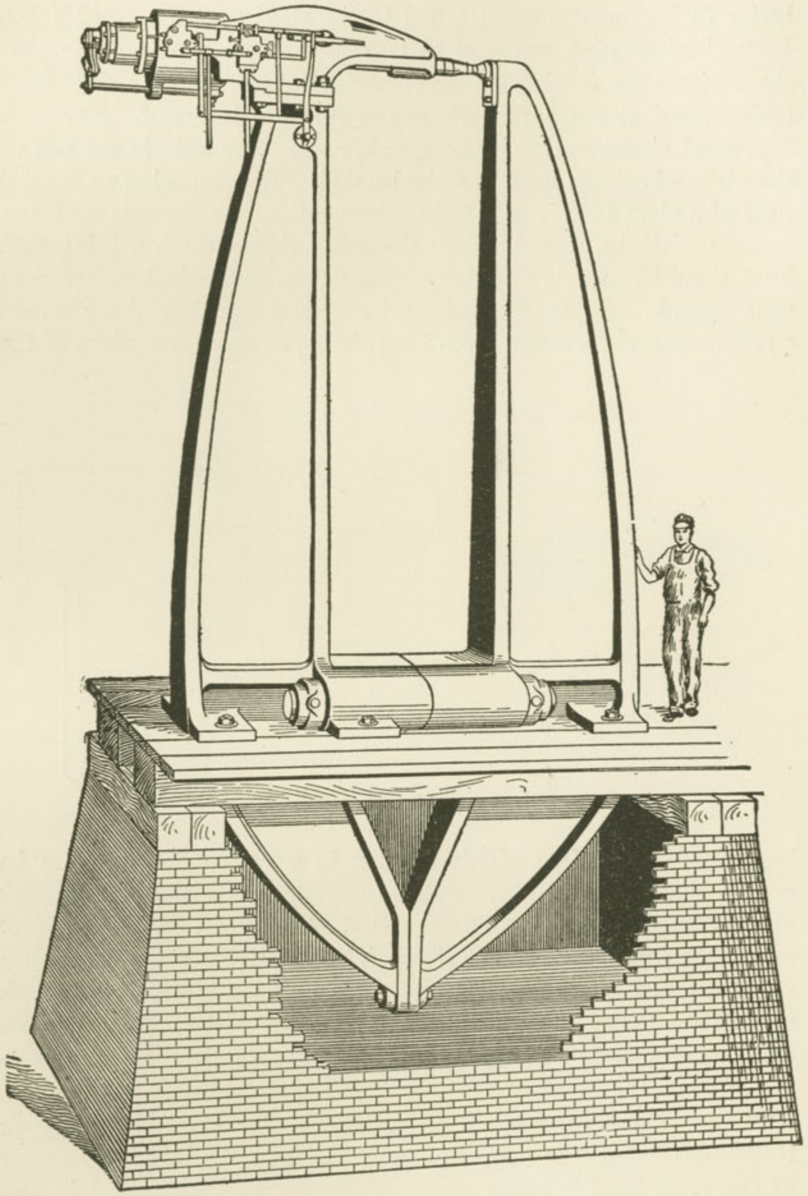


Fig. 40

the surface of the outside plate. A rivet passing through two thicknesses of plate is shown in Fig. 38. The portion of the shank projecting beyond the plate is made $1\frac{1}{4}$ times the diameter of the rivet for hand-riveting, and $\frac{1}{4}$ inch longer for machine-riveting. Dotted lines in this figure show the conical head formed by hammering down the shank of the rivet with light hammers. This conical head can be made more rapidly than the other standard forms when only hand tools are available. The cup-shape head is, however, often made with hand tools by hammering down the hot shank very quickly and finishing off with a cup-shape die or stamp D shown in Fig. 39. The die is placed on the partly finished head and the rivet is shaped by the force of several blows struck on the back of the die with a heavy hammer. A completed rivet with two cup-shaped heads is shown at C in the same figure.

Practically all riveting is now done with machines usually operated by hydraulic pressure; but pneumatic and steam riveting machines are also used to some extent. Hand-riveting is done in large boiler shops only when the space around the rivet hole is too small to get a machine in position. Formerly, all riveting was done by hand, but machine-riveting has superseded the hand methods wherever a machine can be used. With the machine, riveting can be done so much more quickly than by hand, and the work is more uniform in quality and strength. When riveting is done by hand it is often observed that a small shoulder has been formed in the rivet hole near the head of the rivet, because the metal has not been properly hammered and the hole is not completely filled. With these conditions we are likely to find many loose rivets to be cut out and replaced.

Hydraulic riveting machines are most generally used for heavy work on boilers. In fact, no other kind of machine can be successfully used on the heavy plates for marine cylindrical boilers. It is almost impossible to secure tight joints with plates more than an inch thick, except with a hydraulic machine. With this machine work can be done more accurately than by hand, and the enormous pressure which can be applied upsets completely the shank of the rivet, fills the hole before the rivet head is made, and closes the plates tightly; all in an instant and yet without the slightest indication of a blow or impact. This represents the ideal condition for good riveting. Hydraulic power in a boiler shop is easily and conveniently transmitted through pipes.

Hydraulic riveting machines may be fixed or portable. The largest machines are always stationary, and a good example of this class is shown in Fig. 40. The machine consists of two heavy cast steel beams, called stakes, fastened together near the middle and at the lower end. These stakes are made to be of sufficient strength to withstand the stresses produced when forming the rivet head. A hydraulic cylinder is located on the top of one of the stakes, and the other carries the fixed die. The heading tool or stamp, usually cup-shaped, is attached to the end of the hydraulic ram. The plates to be joined with rivets are placed in the proper order between the fixed die and the stamp at the end of the ram, and the operator puts the hot rivets into the holes; then by pressing a small lever the ram is pushed out from the cylinder and the head

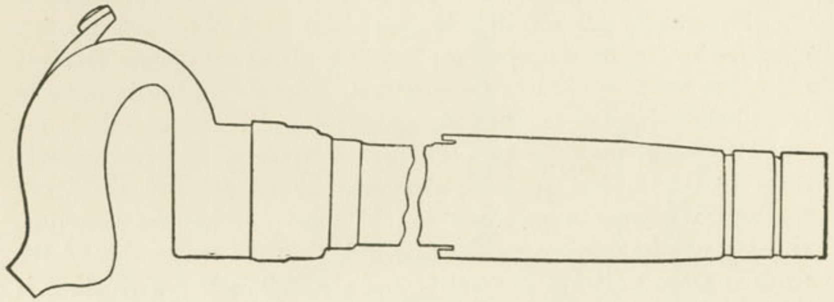
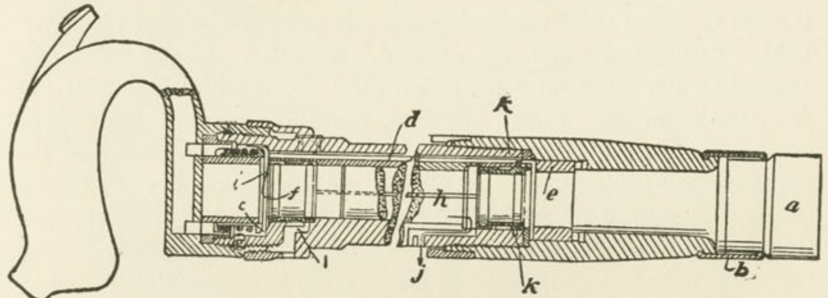


Fig. 41

is made. The size of plate that can be handled in the machine is limited by the distance or reach between the riveting dies at the top and the bed plate at the middle of the machine.

The machine shown in Fig. 40 is a triple-pressure type. The areas of the rams in the cylinder can be adjusted to give three different total pressures on the heading tool, so that plates of various thicknesses can be riveted with approximately the right amount of pressure. Thick plates and rivets of large diameter require more pressure than thinner plates and smaller rivets. Three different pressures can be obtained by operating the simple two-way valve at the side of the machine. A hydraulic accumulator is the direct source of power supply for the machine. For this machine the pressure in the accumulator is 1,500 pounds per square inch, and the three total pressures obtained at the machine are 50, 100, and 150 tons.

Pneumatic Riveting Machines. In addition to hydraulic riveting machines, which have such an important part in modern boiler shop practice, pneumatic riveters, operated by compressed air, are also employed with good success, especially for work to be done where the space is limited. Some authorities argue that the succession of sudden blows from a rapidly moving pneumatic riveter tends to crystallize the material of which the rivet is made, and, like hand-riveting, does not permit the metal to flow readily to fill the hole before the head is made. The extremely rapid action of the hammer in this machine seems to overcome the second objection satisfactorily, as the metal has no time to cool, and that serious crystallization takes place is very doubtful. Excellent results, at any rate, are reported wherever these machines are used.



SECTION OF BOYER LONG STROKE HAMMER.

Fig. 42

The Boyer long-stroke riveting machine of this class has been very successfully employed in the U. S. Navy. It has been used satisfactorily on $1\frac{1}{4}$-inch rivets.

An excellent article from the *American Machinist* of April 25, 1901, involving a description of the Boyer long-stroke pneumatic hammer, is reproduced as follows:

This tool, shown in Fig. 41, and section herewith, is the result of a series of experiments having for their object the development of a hammer which should deliver as powerful a blow as the materials of which it is made are capable without destruction to themselves. To this end the piston is a simple cylinder without grooves or shoulders of any kind, it being considered that in working the piston to its capacity that capacity would be greater without such grooves.

Fig. 42 shows the hammer with a riveting die "a" in position, the action of the valves being also shown. The throttle valve is located in the usual place in the handle, where it is conveniently placed for operation by the thumb. The opening of this valve alone is not, however, sufficient for starting the hammer. The blow of the piston is delivered directly on the shank of the die, which is prevented from falling out of the die by a light clip "b" only. Should the air be turned on before the die is pressed against the rivet the first blow would send the die and piston flying through the air, resulting in possible injury to someone or to the loss of the pieces. A second stop valve "c" is therefore employed which is operated by two rods, of which one is seen at "d," which extend down through the body of the hammer, their lower ends resting on the ring "e" against which the die shank abuts. So long as the die is off its rivet the spring and air pressure behind valve "c" hold it firmly to its seat, the rods "d," ring "e," and die "a" being pushed to the right, and hence opening the thumb valve will not start the hammer. When, however, the die is pressed against the rivet, valve "c" is opened, and if the thumb valve is also open the hammer will operate. Valve "c" is, of course, open wide or not at all, the control of the blow being entirely by the thumb valve. The operator is, in fact, unconscious of the presence of the valve "c." He only knows that the hammer must be in position for work before it will operate, and, except for this fact, the hammer behaves precisely as though there were no valve "c."

The valves which control the blow of air to and from the two ends of the cylinder are shown at "f" and "g," and are hollow, very light, and short of stroke. Light rods similar to but smaller than "d" lie between the valves in the walls of the cylinder. One of these rods is shown at "h." As each valve moves toward the center of the cylinder to admit air at its end, it, through these rods, pushes the other valve away from the center to exhaust the air from its end.

In the position of the parts shown, the air enters the upper end of the cylinder as shown by the arrow "i," and drives the piston downward, the exhaust escaping as shown by the arrow "j." As the lower end of the piston enters the valve "g" it compresses the air before it. This cushion pressure acting on the ring end of "g" pushes it to the left, the valve "f" being also pushed to the left through the action of the rod's end. In this position the parts which

were previously open are closed, while port "k" is opened to live air and port "l" to exhaust, the holes in which rods "d" lie serving also as passages to carry the air to the port "k." On completion of the return stroke the piston enters the upper valve "f," when the action of the cushioned air is to push the valves to the right.

From the designer's standpoint this machine is remarkable, in that its action is independent of the length of the piston. The piston may be removed and a longer or shorter one be substituted with a corresponding change in the length of the stroke, without in any way changing the correct action of the parts. By thus changing the pistons, blows of different character can be obtained.

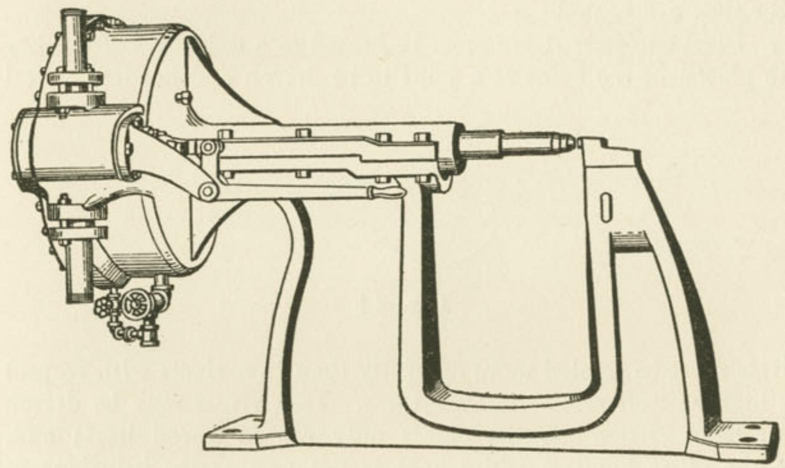


Fig. 43

Steam Riveting Machines. Steam riveting machines have been practically replaced by those using hydraulic and pneumatic pressures. Low steam pressures have always been used, so that extremely large cylinders were necessary compared with those of other machines. This difficulty could, however, be remedied if these machines were not undesirable for other reasons. The sudden and hammer-like blow delivered by a steam riveter corresponds exactly to the blow of a hand hammer, and there is no doubt that this tends to crystallize the rivets very seriously. Experience shows that steam riveters do not properly fill the rivet holes with metal. Fig. 43 shows a steam riveter using 100 pounds pressure.

Strength of Rivets. Rivets are not as reliable for tension stresses as for crushing or shearing stresses. For this reason, when forces are to be resisted which would be exerted along the length of a rivet, bolts are used instead of rivets.

There is very little difference between the shearing strength of iron and steel rivets. In shear steel rivets will resist about 45,000 pounds per square inch, and iron rivets about 40,000 pounds per square inch. Steel rivets are often used with steel boiler plates, but there are some boiler makers who use iron rivets for all work. Their reason is that there is not much difference in the relative strength of the two materials for use in rivets. Steel rivets must be handled much more carefully than iron rivets whenever they are heated.

Steel and iron rivets must be heated to a red heat before they are placed in the holes at a joint to be driven and headed. Steel

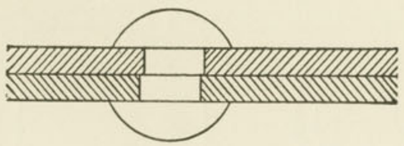


Fig. 44

rivets must be treated more carefully than iron rivets with respect to high as well as low temperatures. Iron rivets may be driven and hammered when the points only are at a red heat; and, on the other hand, a white heat is not necessarily injurious to their quality. For riveting joints in boiler plates, steel rivets must be subjected to a uniform heat, giving a cherry-red color over the entire surface, over the head as well as the shank. If the temperature of steel rivets is too low they will not fill the holes, and loose rivets will result. When steel rivets are exposed to a white heat they are liable to be burned. The fires in the furnaces for heating rivets, re-heating for flanging, and annealing steel plates should be kept thick and at a uniform temperature without much draft.

The greatest possible precaution should be taken that the plates to be riveted are close together, and that the rivet holes are exactly opposite each other. If these precautions are neglected a shoulder will be formed between the plates, so that the strength of the joint is very much reduced. Fig. 44 shows an example of a

shoulder formed by the rivet holes being not exactly opposite each other.

When two plates which are to be riveted together have had all the holes drilled or punched separately, the plates must be brought together with the holes in one plate in alignment with the corresponding rivet holes opposite. Usually a few bolts are temporarily put through a few rivet holes to hold the plates together, and a *drift* (Fig. 45) is then used to "clear out" the holes. The use of this tool to *force* the holes to correspond cannot be too severely condemned. The metal near the holes suffers severe injury from such forcing, and such practice is absolutely prohibited for all naval and high class work.

When loose rivets are to be removed, or when a riveted joint is to be broken open, a hand chisel is used to break off the head of

Fig. 45

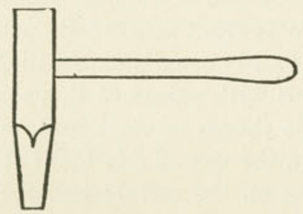


Fig. 46

the rivet, and a punch (Fig. 46) is used to drive out the shank of the rivet.

Testing Rivets. The common tests for the quality of rivets can be easily performed in any boiler shop. The following simple tests should be made, and if the rivets are of satisfactory quality they will show no flaws or cracks:

1. Bend the shank of a hot rivet down upon itself.

2. Bend the shank of a cold rivet around the shank of another rivet of the same diameter to form a hook.

3. Flatten out the head of a hot rivet till its diameter is $2\frac{1}{2}$ times the diameter of the shank.

Calking of Riveted Joints. To make the riveted joints in steam boilers secure against the leakage of steam, the edges of the plates at the joint are hammered together in the process called calking. After riveting a lap joint (Fig. 47) the edge of the overlapping plate is forced down or burred into close contact with the lower plate with a steel hand tool shown in the figure, held usually at an angle of about twenty degrees. In this position the tool is struck repeatedly with a hammer till the edge of the overlapping plate is sufficiently upset to make the joint steam-tight. In the process of calking the tool is moved along the edge of the plate

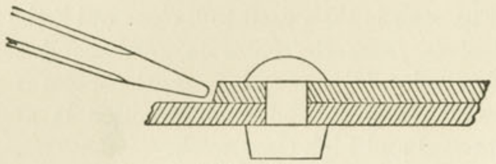


Fig. 47

to give the effect of a continuous seam rather than the effect caused by a great deal of hammering in isolated spots.

To prevent cutting the surface of the lower plate the point of the tool is usually made slightly rounded, as in Fig. 47. Calking tools with points of this shape are called " round nose " tools. The one shown in the figure has a well rounded point. The difficulty in the use of this tool is that it is hard to make the first impression on the metal; and for this reason a similar tool with a sharper nose is used to start the work. All calking tools are slightly chisel-shaped. Tools with nearly square-shaped ends are

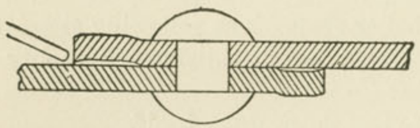


Fig. 48

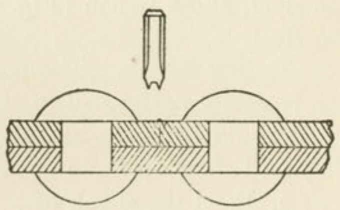


Fig. 49

sometimes used instead of " round nose " tools, because it is said that work can be done more rapidly with them. A square-ended tool is illustrated with the indentation it makes in Fig. 48. When this kind of tool is used the lower plate is liable to be cut by the sharp corners, and the portion of the plate between the calked edge and the rivet is often separated or forced from the other plate, as

in Fig. 48. Flat-ended tools of various forms are very common in boiler shops.

If a slight bevel is given to the plates when the edges are planed, calking is more easily performed.

Careless calking on the inside of a boiler, cutting or forcing the plates apart, often causes grooving and leaves space for injurious deposits of scale. Fractures of boilers examined after an explosion are often found to follow the lines of the grooves cut in the plates by calking.

Fig. 49 illustrates the method and the hand tool used for calking a butt joint. The grooved tool forces together the metal of the two plates at the joint.

Boiler Tubes. The small tubes ($1\frac{1}{2}$ to 3 inches in diameter) for tubular and water-tube boilers are not made in the boiler shop, but as they form such an important part of modern boilers some space should be taken to explain their manufacture. The boiler maker buys his tubes cut to the length he desires, and the diameter of the tubes is so accurate that they are not measured before holes to fit them are cut in the tube sheets.

There are two kinds of tubes in common use: (1) Lap-welded, and (2) cold-drawn seamless. *Welded tubes* are usually made from sheets of charcoal iron* cut and bent to form a circular section. Before bending, however, the edges of the plate are upset to about double the thickness of the original plate. The tube is bent, of course, so that the upset edges overlap sufficiently, and is then put into a furnace in short portions of about eight inches at a time to be heated to a welding temperature. These short lengths of tube at a white heat are then hammered over a mandrel till a weld is formed. For this kind of work a mandrel is simply a cast iron stationary bar or " arm " with a curved top to nearly fit the curvature of the tubes.

Seamless steel tubes are made from mild open-hearth steel, which is received from the mills in billets or round bars from three to four inches in diameter and from eight to ten feet long. These heavy steel bars are put into a gas furnace and brought to a cherry-red heat before they are sawed into smaller sizes suitable for handling in the " piercing mill," where the real making of the tube in

* Charcoal iron is made by using charcoal for fuel in the blast furnace instead of coke.

the rough is started. One of the simplest forms of this machine is illustrated in Fig. 50. It consists of two cast steel discs A and B mounted on two shafts of which the center lines lie in the same plane. The shafts revolve in opposite directions, as indicated by arrows in the discs. The distance between the faces of the discs can be regulated by adjusting screws to permit taking into the machine billets of various diameters.

After the original billet received from the steel mill has been cut up into lengths suitable for the "piercing mill," these short pieces are placed in a re-heating furnace and brought this time to a yellow heat. The "piercing mill" is provided with a guide designed to support the hot billet while it is fed in between the discs till its end is caught between the two opposite revolving surfaces.

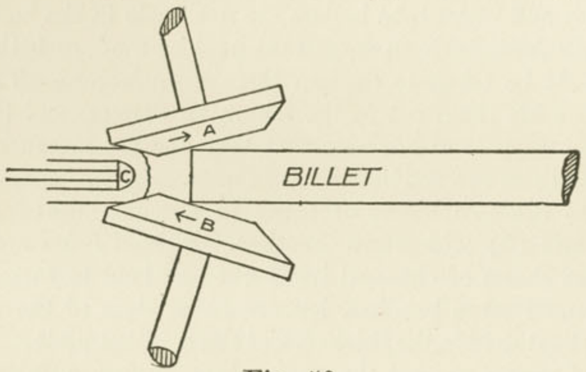


Fig. 50

The same principle that carries a belt to the highest part of a rim of a pulley keeps the end of a billet at the narrowest space between the discs. The machine takes its name from the piercing point C shown here inside the hollow tube at the left of Fig. 50. This steel point pierces through the middle of the advancing billet at the same time that the discs roll out and make smooth and true the outside surface of the tube that is forming. The piercing point is firmly supported at the other end, so that it enters the center of the billet. This support is not, however, rigid, but allows the piercing point to take up the motion of the billet as it is revolved by the discs. In order to keep the discs at a temperature which will not remove their temper they are constantly cooled by a stream of cold water.

If the billet is not cooled too much in this passage through

the "piercing mill" it will come out with a smooth central hole, while its length will be about twice the length when entering. This hollow billet when still hot is now passed through a set of rolls like those in rolling mills for making steel beams and other structural shapes, except that each time the hollow billet passes through the rolls it is fed over the point of a mandrel supported rigidly between and close up to the rolls. In the tube mill each passage of the billet through the rolls is called a "pass," and 5 to 8 passes are required to produce a hollow cylinder or tube of uniform thickness. After each pass the billet is turned around through 90 degrees in order that the rolling may be well distributed over the surface. After this rolling the billet is from 4 to 5 times the original length with which it started through the "piercing mill,"

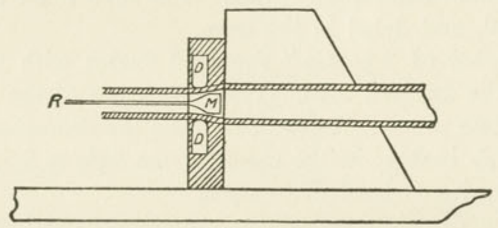


Fig. 51

and the thickness is ¼ inch greater than that for the finished tube. This thick tube is then cooled to the temperature of the air in the shop, while one end of the tube is hammered down to a point, so that this part can be started through a die of smaller diameter than the tube.

When the tube has been cooled to "room" temperature it is carried to the pickling room for the removal of scale in an acid bath in long troughs. The scale results mostly from the heating before the rolling process, but it is quickly removed in a weak acid bath, and after a thorough washing in water the tube is ready for the finishing processes.

The tubes next go through the process called "doping," which consists in immersing them in a mixture of tallow and flour paste and afterwards drying in a baking oven. The "doping" process gives a surface which makes easier the drawing of the tube that follows. The end of the tube was closed up and pointed before pickling to prepare it for this process. A die used for drawing boiler tube is shown in Fig. 51. Into the open end of the tube a mandrel M is pushed till it comes up against the closed end. This mandrel is supported at the end of a long rod R fastened to the draw bench to hold the mandrel in the proper position with respect to the die. When the tube is ready for drawing, the closed end with the mandrel inside is forced into the die D. The pointed end penetrates to the other side, where a man grips it with a pair of drawing pliers. Some "toes" attached to the pliers are fastened to an endless sprocket, which is not shown in the figure. The chain moves along slowly and draws the whole tube through the die D, each drawing operation reducing the tube in thickness and lengthening it about 20 per cent, while it makes the inside and outside very smooth and true. The tubes must be drawn through the dies several times in order to accomplish a sufficient reduction in thickness; and after each "pass" the tube must be annealed, pickled, doped, and dried in the oven.

The number of "passes" required varies with the size and thickness of the finished tube. Two-inch tubes of the usual thickness require two passes. In the first pass the diameter is reduced from $2\frac{1}{2}$ to $2\frac{3}{16}$ inches; in the second from $2\frac{3}{16}$ to 2 inches. One inch tubes require at least five passes.

After the drawing operation, annealing, cutting to length, and inspection, the tubes are ready to be sent to the boiler shop.

The dimensions of boiler tubes are given by their outside diameters, and these diameters are always very accurate. In fact, the holes in tube sheets are often cut out before the tubes have been received at the boiler shops. That there is never any difficulty in fitting the tubes if the holes are of the required size argues well for the accuracy of the work in the tube mill.

For marine boilers and high-pressure work generally welded tubes are not accepted. The specifications of the U. S. Navy require cold-drawn seamless steel tubes.

Expanding Boiler Tubes. When the riveting and staying of the boiler shell has been finished, the tubes are put into the holes already made for them in the tube sheets. For the ordinary boiler tubes the holes in the tube sheets should be cut with enough clearance to permit the tubes to slide through easily. Then, after the tubes are in the proper positions in the boiler, they are securely fastened at the ends to the tube sheets. This process of fastening the tubes is called expanding.

There are two common forms of tube expanders. One of these

tools expands the tube all along the thickness of the tube sheet. Another form expands the tube inside and outside of the tube sheet. This second method gives a bearing surface for the tube at only the corners of the tube sheet (Fig. 52), while the method of

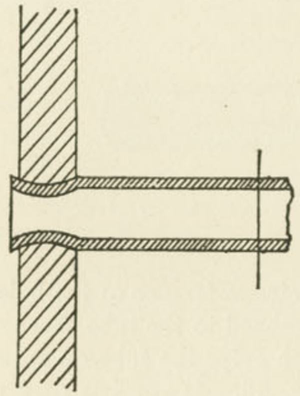


Fig. 52

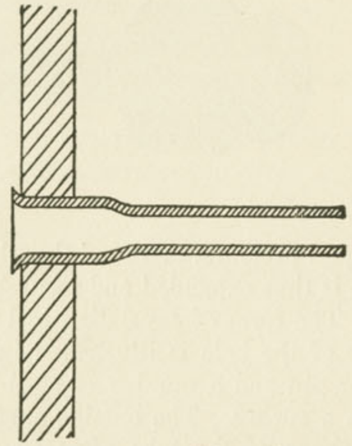


Fig. 53

expanding all along the length of the hole in the tube sheet (Fig. 53) gives much more strength and is the method now generally used in boiler shops. The tool is shown in Fig. 54. It consists of a cylindrical frame F with three steel rollers R for pressing

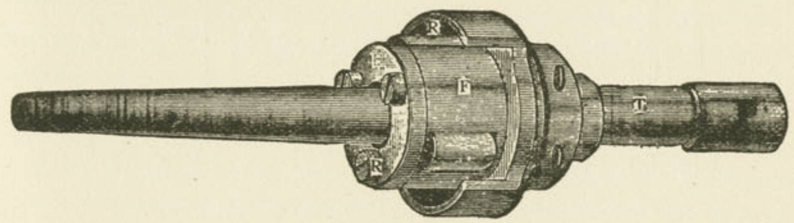


Fig. 54

against the part of the tube within the hole in the tube sheet. These rollers move radially in slots and are pressed out by a tapering rod T. The rollers are allowed to drop into the cylindrical frame F when the expander is being put in position in the opening of the tube. When the tapering rod T is pushed firmly into the frame the rollers are forced out from the center and they press the metal of the tube against the surface of the hole in the tube sheet. This operation is repeated several times, each time revolving the expander so that all points on the surface of the tube are subjected

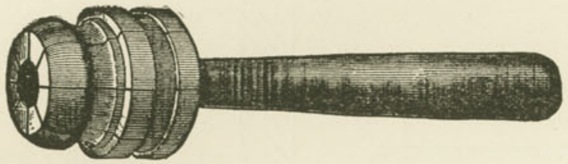


Fig. 55

to equal pressure. Around the whole circumference of the hole the tube is thus expanded and securely fastened to the tube sheet.

The form of expanding tool which grips the tube on only the edge of the hole is illustrated in Fig. 55. It consists of a steel taper pin and a number of steel blocks or segments held together with a spring. The outside surface of the blocks corresponds to the shape of the tube after expansion, while the inside surface

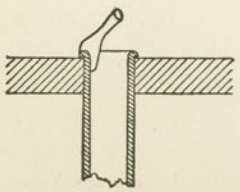


Fig. 56

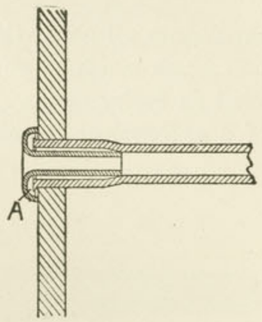


Fig. 57

forms a hollow cone through which a tapering rod passes. By hammering on the end of the tapering rod the blocks are forced apart and expand the metal of the tube around the hole in the tube sheet. This tool must be handled more carefully than the one which was first described, in order that the metal may not be injured. For this reason the hammering should be done slowly and

carefully, while the expanding tool is frequently moved to allow for possible inequalities in pressure from the different blocks.

Beading Boiler Tubes. After the ends of the tubes have been expanded they are beaded in order to add to the strength of the connection. This beading is done with a boot tool shown in Fig. 56 in position after rounding the end of a boiler tube.

This work of beading can also be done, however, with tube beading machines, possessing some advantages over hand work because the work can be done more rapidly, and in the end will be more smoothly finished.

For the purpose of protecting the ends of the boiler tubes from the intense heat of the furnace, ferrules are often attached to the ends of the tubes in the tube sheet of the combustion chamber. This arrangement is indicated in Fig. 57. A small space is left at A, so that air is interposed between the ferrule and the end of the tube. Air is a poor conductor of heat, so that this construction is much better than if the ferrule touched the end of the tube.

Hydraulic Tests of Boiler Shells. Steam boilers should always be tested by hydraulic pressure before they are taken from the boiler shop. Hydraulic tests are made to determine the strength and tightness of the boiler without risking the danger of an explosion that might result if steam were used. Water is practically incompressible, so that if any point of the boiler shows signs of rupture or giving way by leaking along a seam the pressure is immediately relieved. By hydraulic testing, then, defects in materials and in joints are easily discovered without risk of personal injury or damage to buildings.

A purchaser should always insist that a satisfactory hydraulic test is made by a competent inspector before a boiler is accepted, and in the meantime steam pressure should not be permitted in the boiler.

The hydraulic test is also of much importance to the boiler maker. It is an infallible method of discovering poor and careless workmanship in riveting. The great pressure which is used for the hydraulic test will show small leaks at seams that would not be discovered with steam pressure. The boiler maker has also learned that these tests give a method of estimating the strength of irregular shaped surfaces which could not readily be calculated with accuracy. The data is obtained by observing the stretching or bulging of surfaces by careful measurements. The cylindrical shell of a boiler is stretched so slightly and so uniformly that measurements on the shell are not so useful as on flat surfaces. Careful measurements of the deflection of boiler heads, combustion chambers, and internal flues give useful information regarding the working of the boiler under the required pressures.

Old boilers are sometimes subjected to a hydraulic test for proving the tightness of joints at repaired sections; but the test of an old boiler by hydraulic pressure must not be accepted as showing that the boiler is safe without systematic examination by a skilled inspector.

The pressure required for a hydraulic test of a steam boiler is from 1½ to 2 times the rated or working pressure. The water used for the test should be at nearly atmospheric temperature, as leakage is then more easily observed. If warm water is used, the leakage from very small cracks will evaporate and thus escape detection. The boiler should be completely filled with water; that is, provision must be made for the escape of air from the boiler, so that it will not be compressed and held in the boiler. Air in the boiler makes pumping more difficult, and some little time is required to compress it. This compressed air, on the other hand, constitutes a supply of stored energy comparable to steam under pressure, which in case of a rupture will expand, increasing the size of the hole and probably projecting the detached parts with great force. There are, of course, many small cavities caused by the overlaps of seams, etc., which cannot be filled, while all water contains some air in suspension, so that always a certain amount of pumping is necessary to produce the required test pressure when all joints are tight. When, however, the required pressure has been reached, it should be maintained by a few occasional strokes of the hydraulic pump. The test pressure is usually held on a boiler for half an hour.

Steam pressure should never be used on a boiler for testing purposes. It cannot reveal leakage as well, and several explosions have resulted from this dangerous practice.

THE LAYOUT OF PLATES.

There are two general methods employed in laying out plates in the boiler shop:

a. The drawings are made to full scale on the plate to be used and the plates are cut to these lines, no other drawings being required. This is the practice most generally employed in large work and in work which is not likely to be duplicated.

b. The drawings are made on drawing boards or smooth floors and are then transferred to the plates. There are two methods of transferring these lines to the plates: (1) By making a templet, which can be laid on the plate and the lines marked out, following exactly the lines of the templet. The templet is usually made of wood or iron. Wooden templets are cheap, but they have the great disadvantage of shrinking and curving out of true. Wooden templets for plates are, however, often used and are framed together with narrow strips. If the templets are to be used over and over again they must be made of iron. They are made of thin plate of from ⅛ to ¼ inch in thickness, and all parts not actually in use are cut out to make the plate light and enable the plater to lift it around easily. These templets are very strong and are almost indestructible. (2) The second method of transferring these lines to the plate is to use trammels, straight-edge, chalk-line, compasses, etc. This method is used in the case of jobs done singly or work that is not likely to be duplicated.

Almost all work for plating and boiler-making is marked out to full size before being proceeded with. In the case of standard work this is not done, as templets are at hand to mark out the plates. It is necessary to lay out plates to full size, because as in all engineering work absolute accuracy can be had in no other way. Absolute accuracy cannot be obtained by mere calculation, as there is always the probability of a concealed error. Moreover, the relation of many parts can be seen only on marking out, and a man can always judge his work better from a full-size drawing than from a scale-drawing. By actually laying a plate out to full size, errors in scale-drawing are often unearthed. In general, then, it is advisable to lay out work to full size, and in many cases it is necessary.

The method of marking lines on the plates or boards varies considerably with the maker and with the class of work being done. Plates are generally prepared for marking by whitening them. Chalk is sometimes used for this purpose, but the more permanent method is to use a solution of whitening which should be allowed to dry thoroughly.

Boards may either be whitened or painted black. They may be whitened with either chalk or paint. The white surface is most suitable for small work, while the black is most generally employed for large work.

The manner of marking lines depends greatly upon the size of the work. Those on large drawings are marked with a chalk-line when possible. Very long straight lines cannot be marked so well with a straight-edge as with a chalk-line. The chalk-line should be firm and even tightly strained, and the lines from it will then be fine, clear and true. Curved lines are marked with a trammel or scriber point, and are then set in afterwards with chalk to make them clearly visible. The lines on small drawings or on whitened surfaces are marked with a lead pencil or with a scriber point.

In large work the slightest error in laying down a line is greatly magnified with the length of the line. When the angular relations of lines should be very accurate, they should not be laid down by means of squares or protractors. Geometrical methods should always be used when that is possible. In small work, where a slight error does not seriously affect the size of a plate, geometrical methods are not necessary.

Serious error is sometimes made in using a rule in laying out long lines. In first-class boiler shops a standard rule of from 10 to 15 feet in length is kept for measuring long distances. Errors in the use of a two-foot rule would be so greatly magnified in a long line that the whole job may be spoiled.

Centers should always be marked with trammels, compasses, or dividers, and never with a rule. When marking on a plate, the centers should always be marked with a center punch. On wooden boards centers should be indicated with a cross or a circle, so that they can be observed at a glance. In laying out the plate, circles, which are to be bored out or drilled, should be so indicated. All rivet holes intended to be countersunk should be distinguished in some way from the common rivet hole. If this is not done the common rivets are likely to be inserted, making it necessary to cut them out later and put in the proper rivets.

DEVELOPMENT OF PLATES.

A few principles of plate development will be given here with examples, and by using them the reader can get most any development he desires.

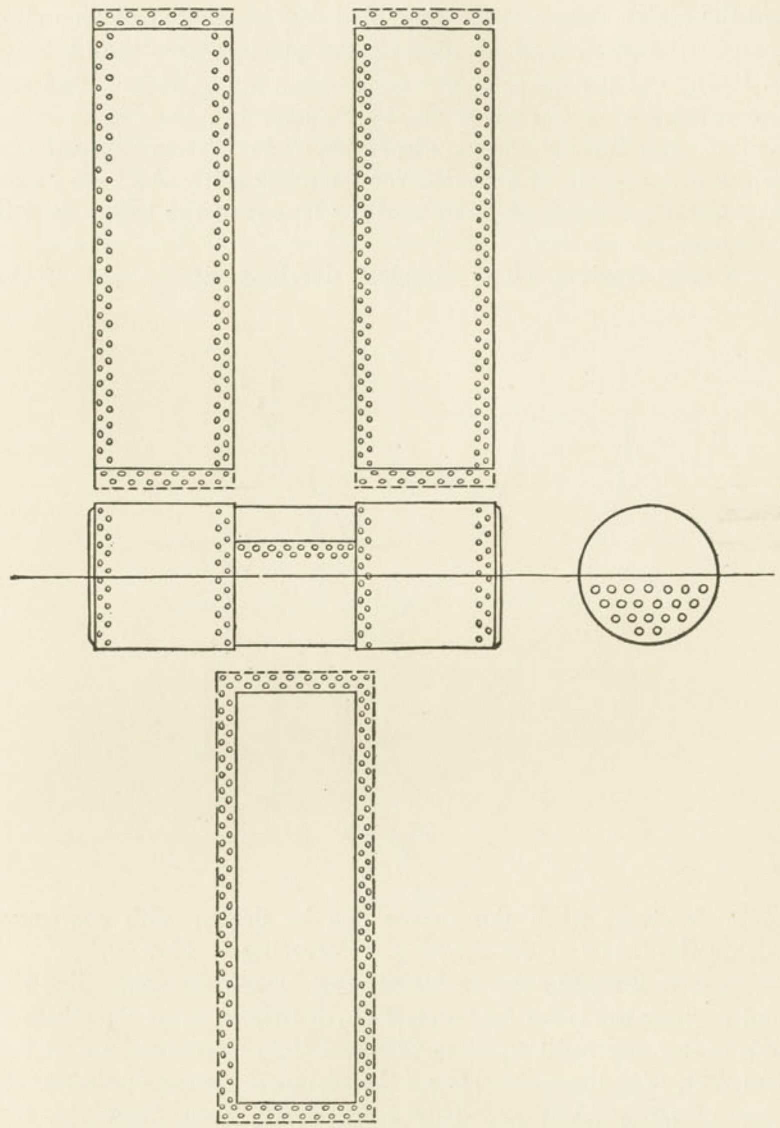


Fig. 58

Development of the Cylindrical Boiler. A clear and concise method of laying out the different plates for a cylindrical boiler is shown in Fig. 58. The boiler is shown in the center assembled and the plates, drawn out to their full developments and true size, are distributed around it, opposite the places where they belong. In laying out the development of the separate cylinders, find the circumference of the cylinders by multiplying the diameter by 3.1416. Lay this out for one dimension and complete the rectangle by using the length of a section for the other side. Add the necessary metal for laps and joints and the layout of the boiler shell is complete.

Conic Frustum. The simplest development is that of the

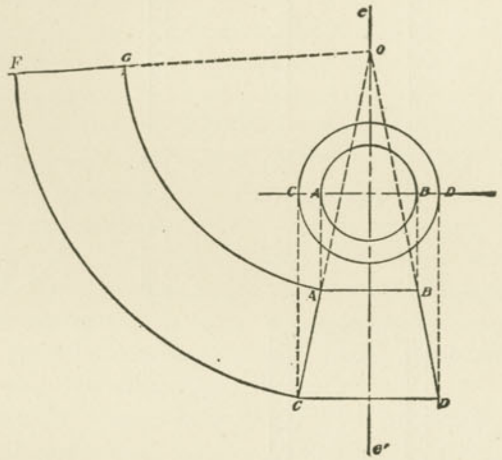


Fig. 59

conic frustum, when the curves can be drawn with compasses within the limits of the drawing. Referring to Fig. 59,

Let A-B-C-D be the conic frustum. Draw the center line e-e_1 and prolong the sides A-C and B-D till they cross at O. With O as a center and radii equal to O-C and O-A, describe the arcs C-F and A-G. On these arcs lay off the distances corresponding to the circumferences A-B and C-D respectively, then draw the line F-G-O. The sector A-C-F-G is then the envelope of the frustum of the cone A-B-D-C, and is the required development.

Telescopic Plates. It is not customary to lay out the development of a conic frustum with reference to the center of a circle of which the frustum when unrolled forms a sector. The limits

of the plate and altitude of the frustum usually make it impractical to use the center method. It could be obtained by calculation, but the method most generally employed is as follows (refer to Fig. 60):

Let A-B-D-C represent the frustum which is to be developed. Determine the circumference of the circles with diameters A-B and C-D. Lay them down at a distance X-Y apart, and divided by the center line e-e^1. Now join A-C and A_1-C_1. Set a square to the edge A-C and draw the line C-N. Then set the square to the edge A_1-C_1 and draw the line C_1-N. Bisect Y-N at D, which

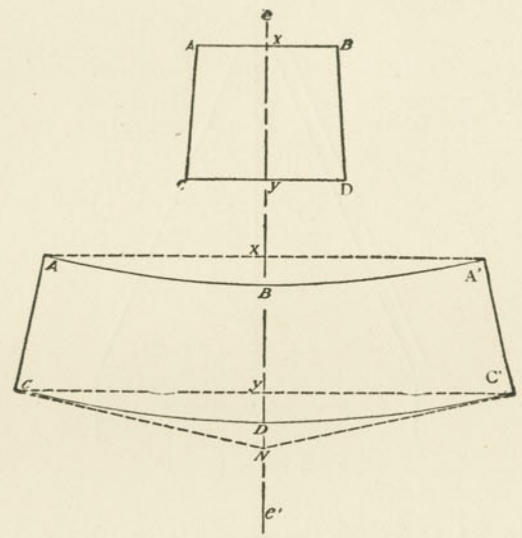


Fig. 60

will be a third point through which the curve C-D-C_1 must pass. From D measure a distance D-B equal to X-Y, and the point B will be the point through which the curve A-B-A_1 must pass. The curves can be drawn by bending a strip of wood until its curvature is such that it will pass through the three points without changing its position. This method of developing a conic frustum is not absolutely accurate, but for all practical purposes is generally found satisfactory. If the frustum has considerable slant this method cannot be used, as the error would then be very appreciable. If D is placed a trifle closer to Y than to N the approximation is very close and more satisfactory.

The development does not allow for riveted joints or for laps of any kind, so that after the development has been made the necessary material must be added to allow for laps and joints.

If the above methods of determining the development of the frustum are not sufficiently accurate, the method of the versed sine can be used and the development made with absolute accuracy. As the former methods are sufficiently accurate for all ordinary cases, the versed sine calculation will simply be indicated.

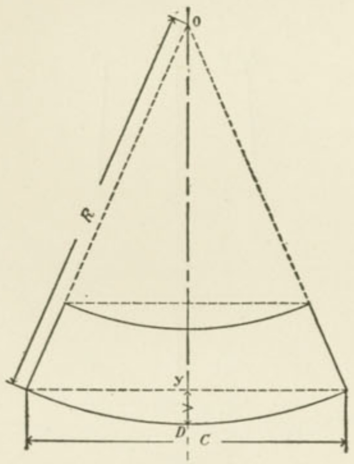


Fig. 61

Let Fig. 61 represent the cone, etc., with the letters noted. Then V is determined as follows:

$$\text{Versed sine V equals } R - \sqrt{R^2 - (\tfrac{1}{2}C)^2}.$$

Square the radius R (which can readily be calculated), from this subtract the square of ½ the chord C, and take the square root of the result. Subtract this from R and the result is the versed sine. After the point D has thus been located, the curve can be drawn, as before noted, by bending a strip of wood to the required curvature.

Development of a Steam Dome. When a cylindrical vessel is

to be fitted to a curved surface, as in the case of a steam dome on a cylindrical boiler, the method of developing is shown in Fig. 62.

Draw a section of the circumference of the boiler and the dome, as shown in (1). Then draw the end view without the lap, as shown in (2). Now in (3) draw the line $M\text{-}M_1$ equal to the circumference of the dome cylinder. Divide the dome circumference in any number of equal parts, the greater the number of parts the more accurate the work. Project the parts, as shown in

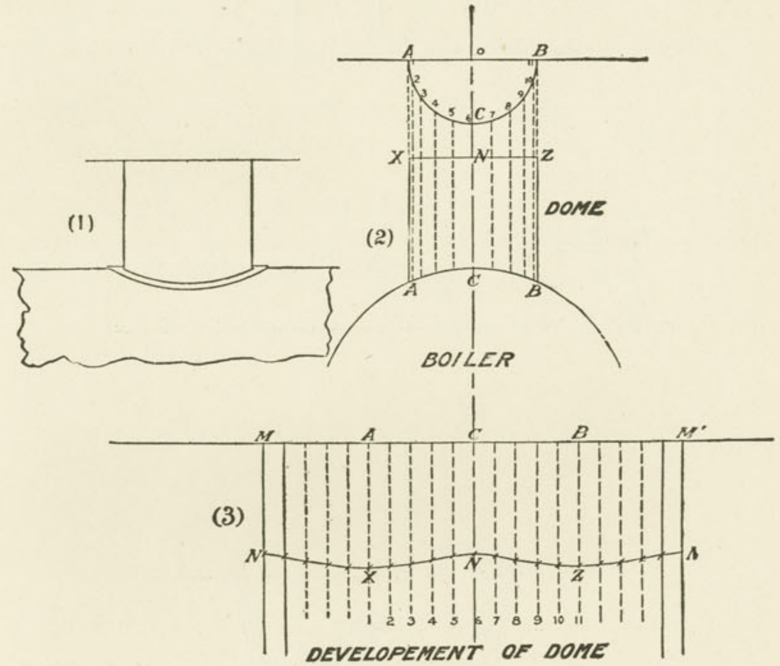


Fig. 62

(2), and divide the line $M\text{-}M_1$ to correspond, drawing the construction lines shown. The plate is now ready for the actual layout of the dome sheet.

Following the system of lettering, lay out the lines on (3) from (2) corresponding to the lines of like letters. Thus, lay out C-N in (3) equal to C-N in (2), and so on until all the lines have been laid out. Then draw the smooth curve N-X-N-Z-N, which gives the development of the plain dome sheet. To this must be added enough metal for the lap joint to fasten the dome together, and also for the necessary lap to fasten the dome to the boiler. These laps are added to the edges of the sheet, and the final layout of the plate to its true size is indicated by the dotted lines.

Development of Slope Sheet. Refer to Fig. 63. The slope sheet is shown in its position in the boiler and the necessary fig-

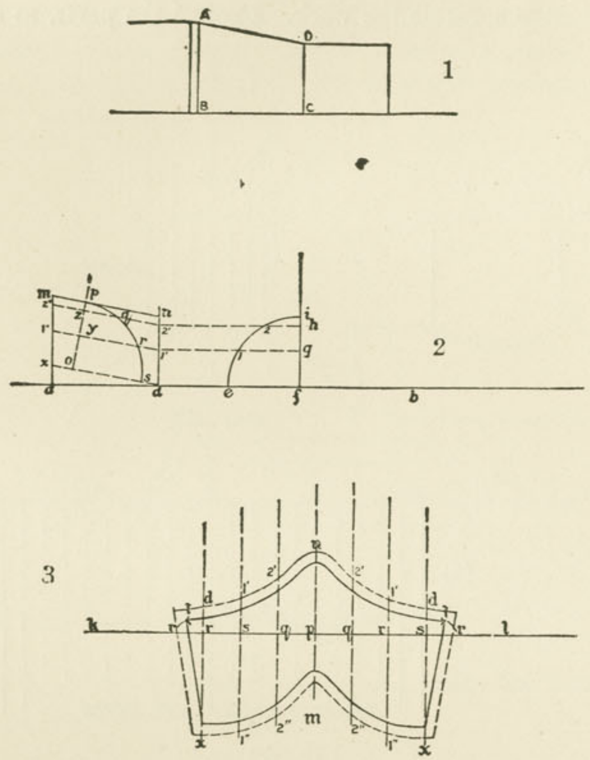


Fig. 63

ures for its development. In part (2) draw the straight line *a-b*, and on it lay off the distance *a-d* equal to large B-C. At *a* and *d* erect the perpendiculars *a-m* and *d-n* respectively, equal to A-B and C-D. With *f* on *a-b* as a center and a radius equal to *d-n*, describe the arc *i-e*. Divide this arc into any number of parts, the greater the number of parts the more accurate the developed envelope. In this case it is divided into three parts at (1) and (2). Project

these points to the line *d-n* at 1′, 2′ and *d*, and draw the lines 1′-1″, 2′-2″, and *d-x* parallel to the line *n-m*.

At any point *o* on the line *d-x* draw the perpendicular *o-p* and describe the arc *p-s*. We are now ready for the development and refer to part (3). Draw the line *k-l* and lay off twice the actual length of the arc *i-e* in six divisions, each division corresponding to one division of the arc. On the line *m-n* lay off the distance *p-n* equal to *p-n* from part (2) and *p-m* equal to *p-m* from part (2); *q*-2′ equal to *q*-2′ from part (2) and *q*-2″ equal to *q*-2″ from part (2), etc., using the notation in part (3) to correspond to that of part (2) until the points *d*-1′-2′-*n*-2′-1′-*d* and *x*-1″-2″-*m*-2″-1″-*x* are all laid out.

With the point *x* as a center and a radius equal to *a-d*, describe the arcs *r*, and with the point *d* as a center and a radius equal to *a-x*, describe the arc *t*, and at the intersection of these arcs connect with *x*, which will complete the development of the plain sheet. Add the part shown by dotted lines for laps, etc., and the finished development is the result.

REVIEW QUESTIONS.

BOILER SHOP AND LAYOUT OF PLATES.

1. Discuss the layout of a boiler shop. Follow a boiler through the shop briefly.
2. Discuss shearing.
3. Describe one shearing machine.
4. How are boiler plates planed?
5. Describe a plate planing machine.
6. Discuss punching.
7. Describe a punching machine.
8. Discuss drilling.
9. Describe a drilling machine.
10. Which is better, drilling or punching?
11. Discuss power required to punch plates.
12. Discuss plate bending.
13. Describe a plate-bending machine.
14. How are plates straightened?
15. Describe a straightening roll.
16. Discuss boiler heads.
17. Discuss flanging.
18. Describe a flanging machine.
19. Discuss welded joints.
20. Discuss riveted joints.
21. Which are better, welded or riveted joints?
22. Discuss riveting machines. The respective advantages of each.
23. Describe steam riveters.
24. Describe Boyer's pneumatic riveter.
25. What advantages has the hydraulic riveter?
26. Discuss the strength of rivets.
27. What are the precautions for riveting?
28. What are the methods of testing rivets?
29. Discuss the calking of riveted joints.
30. How are boiler tubes made?
31. Describe methods of expanding boiler tubes.
32. Describe two tube-expanding machines.
33. Discuss beading boiler tubes.
34. Discuss the practice of making drawings, templets, etc., for boilers.
35. What do you know of the method of laying out cylindrical boilers?
36. Develop the envelope of a conic frustum.
37. Discuss methods of laying out telescopic plates.
38. How would you proceed in the laying out of a steam dome?
39. Describe the development of a slope sheet.
40. Lay out a cylindrical boiler containing a slope sheet and a steam dome.
41. Discuss the hydraulic testing of boilers.

Sheet Metal Work.

To succeed in the sheet metal trade to-day, requires not alone the practical knowledge of sheet metal working, but the technical education necessary to enable one to become foreman, draftsman, or superintendent.

While the trade contains many skilled mechanics, some lack the knowledge required to enable them to lay out their own patterns from the drawings of the various shapes arising in the sheet metal trade. There is no limit to the various shapes met in practice, and while the shapes differ, the principles which will be explained in this course, can be applied to the various problems, making that clear and simple, which would otherwise appear intricate. The elementary principles that underlie the art and science of pattern drafting will be given attention in the following problems, so that when thoroughly understood, they can be applied to similar problems, no matter what change the shape may have. Practical everyday problems will be presented, such as arise in shop practice, thereby giving the reader knowledge which experience only can bring.

SHOP TOOLS.

The tools required for working sheet metal consist of hammer, shears, scratch-awl, compass, plyers, prick and rivet punches, rivet sets for various size rivets, soldering coppers, file, mallet, different size hand groovers, etc. The above are the necessary hand tools for making up short lengths of pipes, transition pieces, offsets, elbows, etc. When pipes are made up in long lengths, they are usually bent in the brake, and seamed with the giant groovers, run by power or hand.

When allowing edges for seaming or wiring, the tools to be used must be taken into consideration, making the required modifications in the patterns so that both pattern and machine will work to advantage. The machines usually employed are the folder for turning edges, the brake for bending pipes, etc.; the burring, turning, and wiring machines for elbow work and seaming, various beading machines with rolls having different profiles, small and large groovers, forming rolls, machine for pieced elbows, the various tinners' stakes, raising hammers, hollow punches, squaring shears, lever punches, lever shears, etc.

Fig. 1

Fig. 2

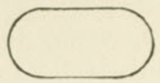


Fig. 3

CROSS JOINTS.

When allowing for cross seams in piping, care should be taken to construct the seams or joints according to the size of pipes used. A small pipe can have a simple slip joint as shown by *a-a* in Fig. 1, soldering the joint if necessary, while a large joint should be seamed accordingly. In Figs. 4 and 5 are shown how round and oblong pipes shown in Figs. 2 and 3 are cross seamed. *a-a,* in Fig. 4, shows the first operation, and *b-b,* in Fig. 5, the finish. Figs. 6 and 7 show respectively the sections of square and rectangular pipes, whose cross seams can be joined by any one of the methods shown in Fig. 8, the strength of the slip *b* to be governed by the size of the pipe in use.

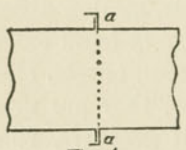


Fig. 4

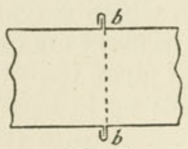


Fig. 5

Fig. 6

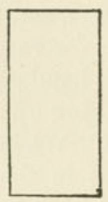


Fig. 7

In the four diagrams A, B, C and D, *a* represents the lower pipe, *b* the slip, and *c* the upper pipe. The slips *b* are riveted to the lower pipes *a,* before the upper pipes *c* are placed in position.

The projections on the slips are placed toward the outside of the pipe, so as not to interfere with its area. When the pipes or stacks are made from heavy metal, they are joined by means of angle-iron flanges, as shown by *a-a* in Fig. 9, the flanges being bolted together.

WIRING AND SEAMING.

In developing patterns for sheet metal work, the patterns are net; that is, there is no allowance made for seams or wiring. After the patterns are developed, laps or edges are allowed according to the kind of seam to be made. In Fig. 10 are shown the various long seams in use, when seaming or riveting the various longitudinal seams in cylinders, stacks, etc. Knowing what seam is to be made, the necessary allowance is added to the pattern. A, in Fig. 10, shows a lap seam to be soldered, while C shows the same seam riveted. B shows a standing seam riveted, while D shows the same seam closed. In seaming large pipes, the groove or seam F is placed on the inside of the pipe, by using the channel bar E, into which the groove G is cut of the required size, the seam F laid on same, and closed tight by using the mallet in the direction of the arrow. This makes the pipe smooth on the outside.

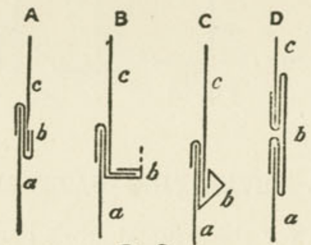


Fig. 8

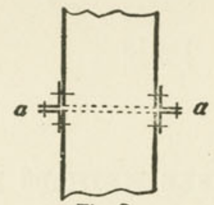


Fig. 9

When stiffening the edges of any sheet metal body, either one of the four methods shown in Fig. 11 can be followed, and allowance made to the pattern accordingly.

A shows a hem edge, B the wired edge, C the band edge and D the angle edge, the metal around the angle iron being closed tight at F with the mallet.

When bottoms are placed in metal utensils, they can be soldered, seamed, or re-enforced as shown in Fig. 12, in which A shows a plain edge, B a double edge, closed as shown by C, or re-enforced as shown by H. In re-enforcing this bottom, E has an edge as shown, which sets over the band iron ring D; the body of the can is then turned over the ring D as shown by F. Rivets are then placed through the band iron and three thicknesses of metal, thus making a strong job. Whatever seam is selected, the necessary allowance for laps must be made on the pattern. In very large work, these seams shown in Figs. 11 and 12 are made by hand; but where they can be worked to advantage the machines are used.

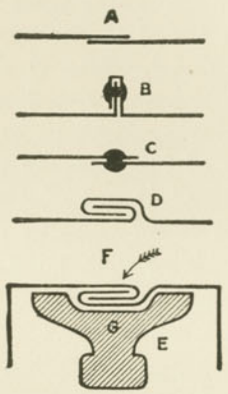


Fig. 10

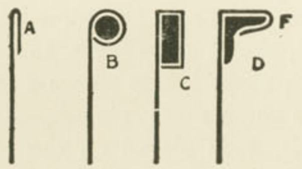


Fig. 11

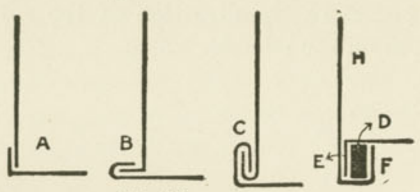


Fig. 12

THREE METHODS FOR DEVELOPING PATTERNS.

In developing all patterns for sheet metal work one of three methods are used, viz.: By means of parallel lines, by radial lines, or by triangulation. In Fig. 13 are shown the principles of *parallel-line* development, also the rules to be observed in developing any parallel form. In this case we take a cylinder as an example.

Let A B C D represent the elevation of a cylinder whose plan or profile is shown by E. Now, if we divide the profile E into equal parts, as shown, and carry vertical lines into the elevation

until they intersect the lines A B and C D, and on the line D C extended as F G place the stretchout or girth of the profile E, and complete the rectangle F G H J, we then have the pattern for the cylinder shown in elevation by A B C D. Obtaining the stretchout F G is the same as if we had unrolled the cylinder from J F to H G. Now suppose this cylinder were intersected by the plane 1′—5′, and it is desired to obtain the patterns for A B 1′—5′ and 5′ D C 1′. Then, having the stretchout of the profile E, it is only necessary to draw horizontal lines from the intersections 1′—2′—3′—4′ and 5′ and intersect similar vertical lines in the stretchout, as shown from 1° to 5° to 1°. Then, L^1 is the pattern for L and M^1 the pattern for M. It makes no difference whether the surface 1′—5′ is a plane, curved, or irregular, the principles are

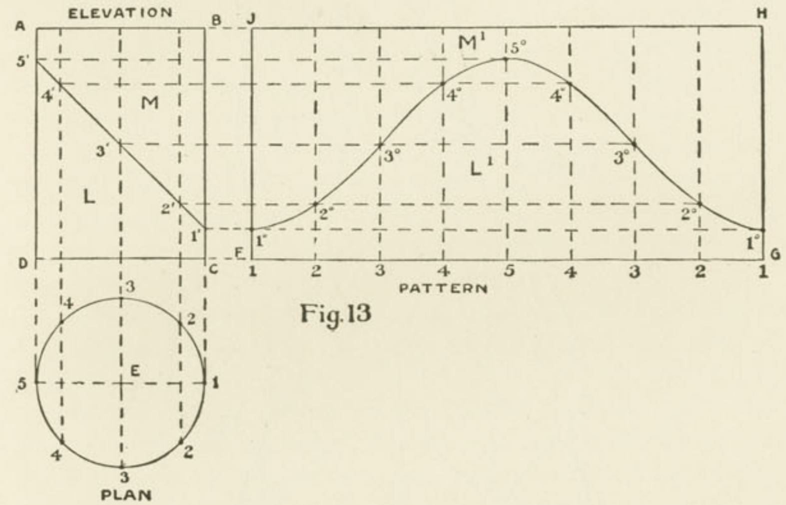


Fig.13

the same. Thus from the above the following rules are established:

(1.) There must be an elevation of the article to be developed, and directly below it the plan or profile.

(2.) The profile must be divided into equal parts, from which lines are carried parallel to the lines of the pipe or article intersecting the intersected line 1′—5′ whether it be straight or irregular.

(3.) The stretchout of the profile of the article to be developed is placed at right angles to the lines of the article as shown by F G.

(4.) From the various intersections on the stretchout line vertical lines are erected and intersected by horizontal lines drawn from similarly numbered intersections on the joint line 1′—5′.

These rules will be applied to all parallel line developments which will follow. In Fig. 14 the principles are explained for *radial*-line development, whether the article to be developed is a right cone, frustum of a cone, or an intersected cone. This method of development is applicable to any form of article, whose base can be inscribed in a circle, the apex of which comes directly over the center of its base, as shown by A in plan and elevation. We shall first consider the right cone A—1′—5′, the

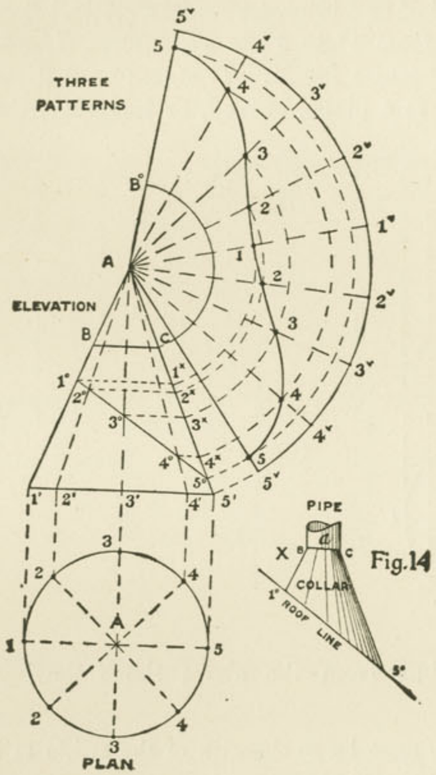


Fig. 14

plan of which is shown by A, which is divided into equal spaces as shown. As the apex A in plan comes directly in the center of the cone as shown by A in elevation, then all radial lines in plan have equal length in elevation as shown by A—1′ and A—5′. Therefore with A as center and A—5′ as radius, describe the arc 5^{v}—5^{v}, upon which place the stretchout of the circle A, as

shown by similar figures on 5^{v}—5^{v}. From 5^{v} draw a line to A to 5^{v} which is the pattern desired.

If the frustum of a cone shown by B—C—5′—1′ is to be developed, it is only necessary to use A as center, and with A C as radius, describe an arc cutting 5^{v}—A, and A—5^{v} at C and B° respectively. 5^{v}—B°—C—5^{v} is the desired pattern.

When the cone is intersected by any straight, curved, or irregular plane, as shown in this case by the straight line 1°—5°, the pattern is obtained as follows: From the various intersections in the plan A erect lines cutting the base of the cone in elevation from 1′ to 5′, from which points draw radial lines to the apex A, cutting the intersected line 1°—5° from 1° to 5°. From these intersections at right-angles to the axis A—A, lines are drawn until they intersect the side of the cone A—5′ from 1^{x} to 5°. Now using A as a center with radii equal to A—1^{x}, A—2^{x}, 3^{x}, 4^{x} and 5°, arcs are drawn, intersecting similar radial lines in the pattern as shown from 5 to 1 to 5. Then B°—C—5—1—5—B° is the pattern for B C 5° 1° in elevation.

B—C—5°—1° in diagram X is a reduced reproduction of similar letters and figures in elevation, showing in diagram X how this problem can be applied in practice for developing a conical collar, around the pipe *a*, passing through a roof having one inclination.

The principles in triangulation are shown in connection with Figs. 15 and 16. Fig. 15 shows the plan and elevation of a transition piece whose base is a rectangle, and top square placed diagonally. 1—2—2°—1° is the plan of the base, and 5—6—7—6° the plan of the top. The vertical height of the transition piece is equal to E 6′ in elevation, the elevation of the entire article being shown by A—B—2′—D. From 5 in plan, draw lines to 1 and 1°; and from 7 draw lines to 2 and 2°. 6 and 6° meet the base lines as shown. These lines then represent the bases of triangles, which will be constructed whose altitudes are equal to the vertical height in elevation.

As the top is placed in the center of the base it is only necessary to find the true lengths of the lines 6—2 and 7—2 in plan. Therefore, take these distances and place them as shown in elevation from 6′ to 2′ and 7′ to 2″ and draw lines to E as shown. E 2″ is then the true length of 7—2 in plan, and E—2′ the true length of 6—2 in plan. If the top were not central in plan the same principles would be used as will be shown in problems which follow.

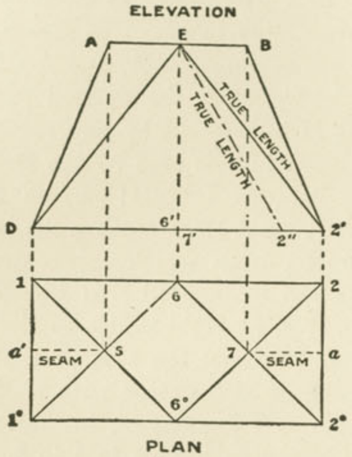


Fig. 15

Having found all the true lengths, the half pattern will be developed as shown in Fig. 16 with seams on *a'*—5 and 7—*a* in plan in Fig. 15. Take the distance of 1°—2° in plan and place it as shown by 1°—2° in Fig. 16. Now with radius equal to E—2′ in Fig. 15 and with 1° and 2° in Fig. 16 as centers, describe arcs intersecting each other at 6°. Draw a line from 1° and 2° to 6°. Using 6° as a center, describe the arcs 5 and 7 with a radius equal to 6°—7 or 6°—5 in plan in Fig. 15. Now with radius equal to E—2″ in elevation and 1° and 2° in Fig. 16 as centers, intersect the arcs 5 and 7 as shown. Now with radius equal to 2°—*a* or 1°—*a'* in plan in Fig. 15 and 2° and 1° in Fig. 16 as centers, describe the arcs *a* and *a'*, and intersect them by arcs struck from 7 and 5 as centers and B—2′ in elevation in Fig. 15 as radius, B—2′ representing the true length on the seam line 7—*a* in plan. Connect lines in Fig. 16 from 1° to *a'* to 5 to 6° to 7 to *a* to 2°, which is the half pattern. While most of transition pieces have circular tops and bases, the one shown in Fig 15 presents the principles which will be applied to various shapes in the problems which will follow.

PRACTICAL PROBLEMS IN HEAVY SHEET METAL.

When sheet metal is used which is heavier than number 20 gauge, it is necessary to make an allowance to the stretchout to make up for the loss in rolling or bending the material. Some mechanics add to the stretchout three times the thickness of metal, while some multiply the thickness of the metal by 3.1416. The best practice is to multiply seven times the thickness of metal used. Thus, if we were using metal ¼-inch thick, we would add to the stretchout 7×¼ or 1¾ inches. If no account is taken of the thickness of the metal, the finished article will measure from center to center of the thickness of the sheet. Suppose a stack was to be made whose inside diameter when finished had to be 30 inches; the circumference would be 30× 3.1416 without allowing for the thickness of the sheet. If ¼-inch metal were used, the circumference would be 30×3.1416+(7×¼).

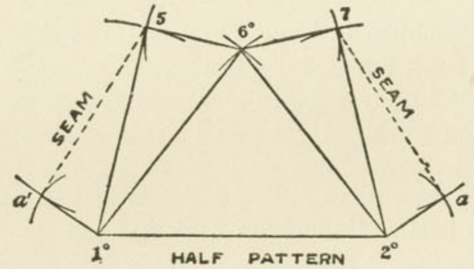


Fig. 16

When articles are to be constructed from heavy metal and patterns developed, the allowance for the thickness of the metal must be equally distributed along the stretchout of the pattern. This will be explained in connection with Fig. 17, in which is shown the practical use of a principle well known to draftsmen, from its application to the proportional division of lines. Let A represent the profile of the pipe on the inside. Divide this profile into any number of equal spaces as shown, in this case eight. Draw any horizontal line as 1—1 in B, upon which place the stretchout of the profile A as shown by similar figures. Assuming that the cylinder A were to be made from ½-inch metal, take 7×½ or 3½ inches and place it to the stretchout in B as shown from 1 to *a*. From 1 erect the perpendicular 1—1° and intersect it by an arc struck from 1 as a center and 1—*a* as a radius, thus obtaining the intersection 1°, from which point draw a line to 1. Now from the various intersections 1, 2, 3, 4, etc., erect lines, intersecting the oblique line 1°—1 from 1° to 8°. This line then represents the true stretchout to which the thickness of the metal has been equally distributed and which is used when developing the pattern.

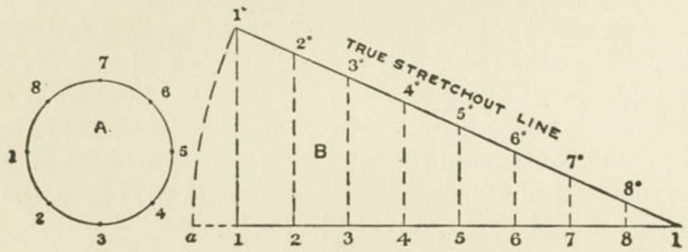


Fig. 17

The first problem in heavy sheet metal is shown in Fig. 18, being a **smoke stack cap** made in sections and riveted. In practice the cap is made in any number of pieces, according to the size or diameter of the stack. If of small diameter less pieces are required than when the diameter is large. No matter how many pieces are used the rule to follow is shown in Fig. 18.

Draw the half section of the stack and cap shown by A; D C representing the center line. While the stack is round, the cap (in this case) will be made in 12 sections, and dropped over the top of the stack as shown. Notice that an angle iron is riveted to the top on the inside of the stack as shown at N and the cap is dropped over this and bolted to the angle iron at P, play room being allowed between the stack and cap as indicated in the section at 11—12 and in plan between the arrow points. Now divide the profile A into equal spaces as shown from 1 to 12, and from the point 4 drop a vertical line intersecting the horizontal line B—H in plan at H. With B as center draw the quarter plan of the stack E—F, and with B—H as radius describe the quarter circle H J. As the cap is to have 12 pieces, divide H—J into three equal parts as shown by L M. Bisect one of these parts as H L, and obtain 5°, through which, from the center B, draw the miter line B—4°. Although the quarter plan is shown completed, all

that is required is that part shown by B—4°—H. Now from the various intersections (1 to 12) in the profile A, drop vertical lines, intersecting the miter line B—4° in plan, from 1° to 12° as shown. On the line B—H extended as 1′—12′, place the stretchout of the profile A as shown. Through these small figures 1′—12′ perpendicular lines are drawn to 1′—12′ and intersected by horizontal lines drawn from similarly numbered inter-

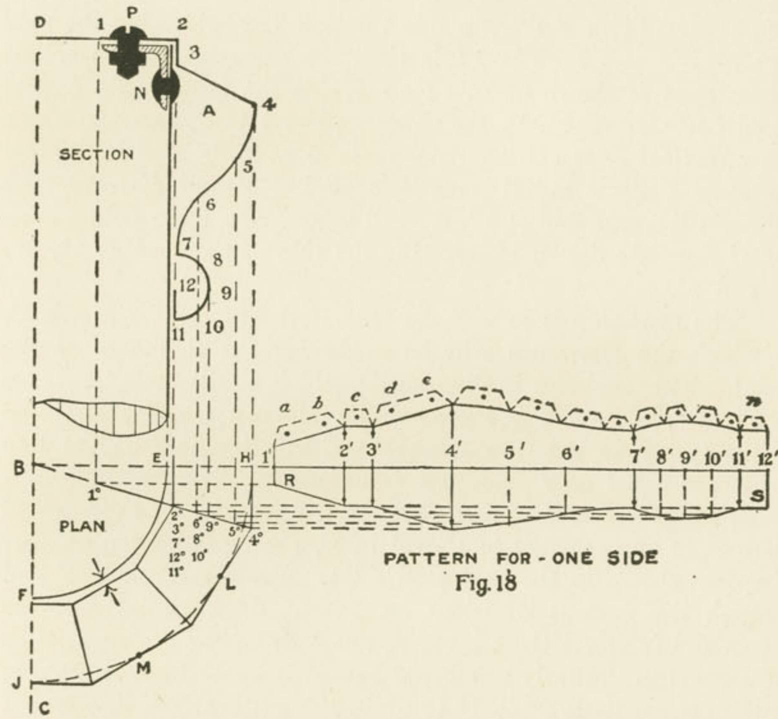


Fig. 18

sections on the miter line B—4°. Through points of intersections thus obtained trace the miter line cut R S. Trace R S opposite the line 1′—12′ as shown, then will R—S—*n*—*a* be the full pattern for one side. Laps for riveting are allowed as shown by *a*—*b*—*c*—*d*—*e* to *n*. No allowance was made in this pattern for the thickness of metal, as in practice it is usual to make the cap of a lighter gauge metal to allow it to be bent in the brake.

Fig. 19 shows the method employed when obtaining the pattern for a **conical collar** to fit around a stack passing through a pitched roof, also showing how the allowance is made for the thickness of the metal. Let A B represent the stack passing through the pitched roof line as shown. Let C represent the half diameter of the outside of the stack and the inside diameter of the collar through 1—5. Draw the center line through the stack as shown, and establish 5″ on the roof line, from which point draw a line through 5, intersecting the center line at F. From F draw a line through 1, intersecting the roof line at 1″. 1—5—5″—1″ is then the elevation of the collar, whose apex is shown at F. Now divide the half-profile C into equal parts, as shown by the small figures 1 to 5, through which draw vertical lines cutting the line 1—5 at 2′, 3′ and 4′. From the apex F draw radial lines through 2′—3′ and 4′ until they intersect the roof line at 2″, 3″ and 4″. From these points horizontal lines are drawn intersecting the side of the cone at 1°, 2°, 3° and 4°.

The next step is to find the true stretchout of the profile C, to which the allowance will be made for the thickness of the metal. This is shown in diagram D, and is similar to that shown in Fig. 17. 1′—*a* in D represents the allowance, and 1^v—2^v one of the spaces in the true stretchout. As all spaces on the line 1—1^v are equal only one space is necessary. Now with F as a center and F—5 as a radius, describe the arc 5^v—5^v, upon which place eight spaces equal to 1^v—2^v in D, (being twice the number of spaces shown in the half profile C). From the center F and through the various divisions on 5^v—5^v draw radial lines as shown and intersect them by arcs, struck from the center F, with radii equal to similarly numbered figures from 1° to 5″, resulting in the intersections 5^x to 1^x to 5^x in the pattern. A line traced through these points, 5^x—5^x—5^v—5^v will be the desired pattern, with a seam on 5—5″ in elevation. Having the seam on the lower side avoids a leak when the water follows the direction of the arrow. A flange is allowed to the pattern for riveting against the stack; flange and rivet holes being indicated by *a b c* to *h* in the pattern.

When heavy metal pipes are to be joined together, and **elbows** constructed, the method of making the various joints is shown in Fig. 20. B A C shows a three-pieced offset, in which the middle

joint A overlaps the pipes B and C. *h, i, j* and *m* representing the rivets.

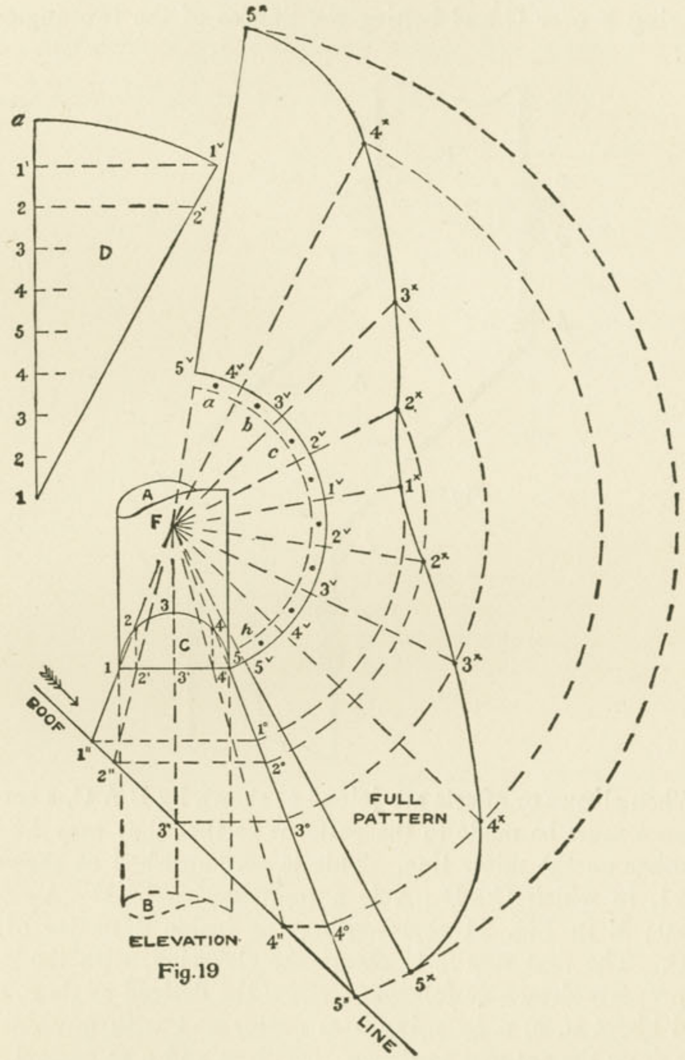


Fig. 19

One method of joining vertical pipes is shown by D. In this case an inside flange is riveted to E at *b*, then the pipe B is slipped over D and also riveted at *a*. Another method is shown at F. In this case angles are shaped to correspond to the profile of the pipe C, and riveted in position as shown by *d*. In a similar manner an angle is riveted to F at *c*. Then the joint is made by placing F over C and bolting the flanges of the two angles as shown.

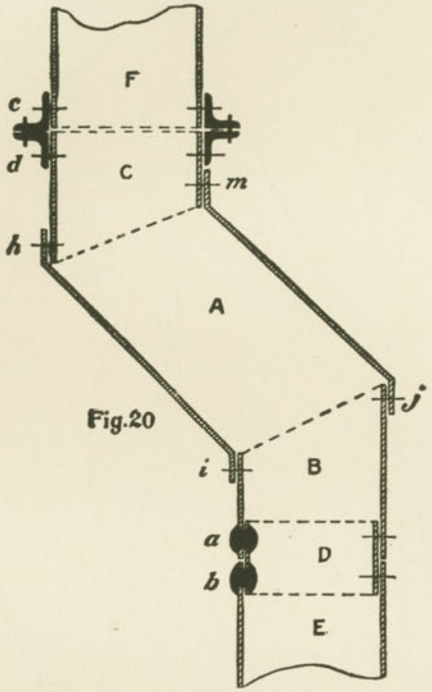


Fig.20

When elbows or offsets are joined as shown by B A C, a certain allowance must be made to the patterns so that they may fit over each other on the miter line. This is accomplished as shown in Fig. 21, in which C—B—A is a reproduction of B—A—C in Fig. 20; E in Fig. 21 representing the inside diameter of the pipe C. The first step is to obtain the elevation, with the miter lines properly drawn as follows: Draw the desired angle *v, u, o, n,* and bisect *u, o, n* by using *o* as center and with any desired radius draw the arc *m n* as shown. With *m* and *n* as centers, and with radius slightly larger than before, describe arcs intersecting each other at *r*. Draw a line from *r* through *o* indefinitely as shown. Establish the diameter of the pipe *n y,* from which erect the vertical line, cutting *r o* extended at *s*. From *s* parallel to *o*

u draw *s t,* which intersect by the vertical line *w t,* drawn from the point *w,* at a horizontal distance from *v* equal to the diameter of the pipe. Draw the line *t u*. As E represents the inside diameter of the pipe C, allowance must be made to the stretchout for the thickness of the metal used, before the pattern H can be

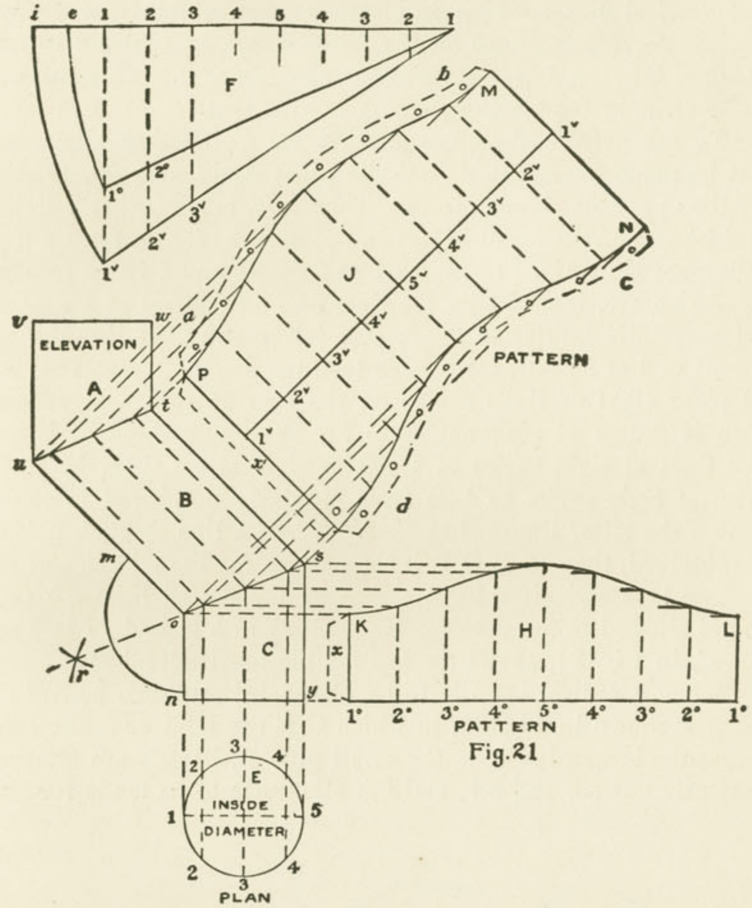


Fig.21

developed. Divide E into equal parts as shown from 1 to 5. Take a stretchout of E and place it upon the line *i* 1 in F as shown from 1 to 1. Take 7 times the thickness of the metal and place it in F as shown from 1 to *e*. From 1 erect the perpendicular 1—1° and intersect it by an arc struck from 1 as center and 1—*e* as radius. From 1° draw a line to 1, and erect a perpendicular from 2 intersecting 1°—1 at 2°. 1°—

2° is then one of the true spaces to be used in developing the pattern for C. Take eight of these spaces from 1° to 2° in F and place them on the line *n y* extended in elevation, as 1°—1° in H. From the intersections in E erect vertical lines intersecting the miter line *o*—*s* as shown. From the divisions on 1°—1° in H, erect vertical lines, which intersect by horizontal lines drawn from similar intersections on the miter line *o s*, resulting in the miter cut KL. A lap is allowed for riveting at *x*. This pattern H also answers for the top piece A in elevation.

To the pattern for the middle piece B, another allowance must be made to permit the middle piece A, in Fig. 20, to slip over the upper and lower pieces. Therefore, take another 7 times the thickness of the metal in use and place it as shown from *e* to *i* in diagram F in Fig. 21. With 1 as a center and 1 *i* as a radius, describe an arc, intersecting the line 1—1° extended at 1^v. Extend perpendiculars from 2—3, etc; intersecting the line drawn from 1^v to 1 at 2^v—3^v, etc. Now take the distance from 1^v to 2^v and place eight of these spaces on the line 1^v—1^v in elevation, which is drawn at right-angles to *t s*. Through these divisions draw lines at right-angles to 1^v—1^v and intersect them by lines drawn at right-angles to *t*—*s* from similarly numbered intersections on the miter lines *u t* and *s o*. Trace a line through points thus obtained, then M N O P is the pattern for the middle section B. The laps and rivet holes shown by the dotted lines *a b* and *c d*, are allowed to the pattern, for flanging at *h m* and *j i* in Fig. 20. x′, in Fig. 21, shows the lap for the longitudinal seam.

When a **conical joint** is to be placed between two boilers or stacks, as shown in Fig. 22, in which C is the joint or taper, connecting the large pipe A to the small pipe B, flanges are allowed for riveting at *a a* and *b b*, and the allowance to be made for the

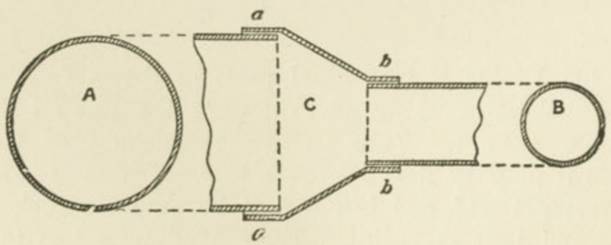


Fig. 22

thickness of the metal to the pattern is shown in Fig. 23. Draw the elevation of the conical joint, as shown by A B C D, making the section through A—B, the outside diameter of the large pipe, and the section through C D the outside diameter of the small pipe. Extend the sides of the cone until they intersect at E, which is the center point with which to develop the pattern.

Now take the stretchout of the large diameter and place it as shown from 1′ to 1. Make the distance 1′—*a* equal to 7 times the thickness of the metal used, and with 1 as a center, and 1—*a* as a radius, describe an arc intersecting a vertical line erected from 1′ at 1^v. Draw a line from 1^v to 1, and from the various

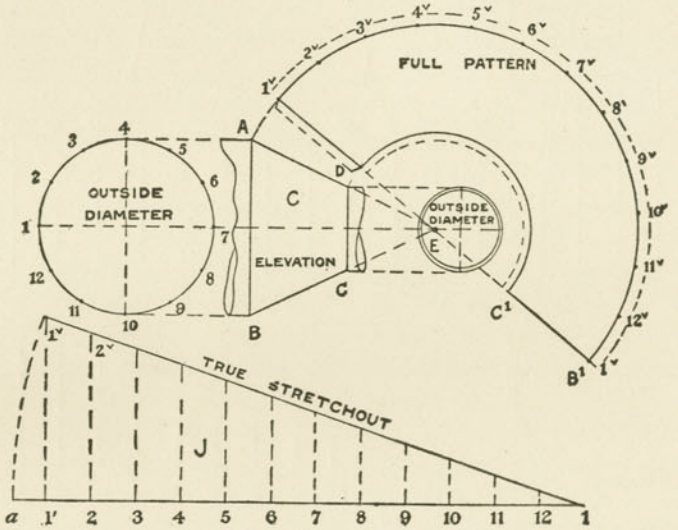


Fig. 23

divisions on 1′—1, draw vertical lines intersecting 1^v 1 as shown. Now with E as a center, and E A and E D as radii, draw arcs as shown.

Set the dividers equal to the space 1^v 2^v in J, and starting from 1^v in the pattern, step off 12 spaces on the outer arc as shown. From B^1 draw a line to E, intersecting the inner arc at C^1. 1^v D C^1 B^1 is then the full pattern to which laps have been allowed for riveting, as shown by the dotted lines.

In Fig. 24 is shown the method of obtaining the patterns for a **steam dome** on a boiler, also the opening to be cut into the boiler. This method is applicable to intersections between pipes of various sizes, stacks, etc. First draw the section of the boiler A, and on its outside diameter draw the elevation of the dome, shown by D. In its proper position draw the plan B representing the plan of the boiler and C the inside diameter of the dome. Divide C into equal parts as shown, from which perpendicular lines are drawn, intersecting the outside diameter A as shown.

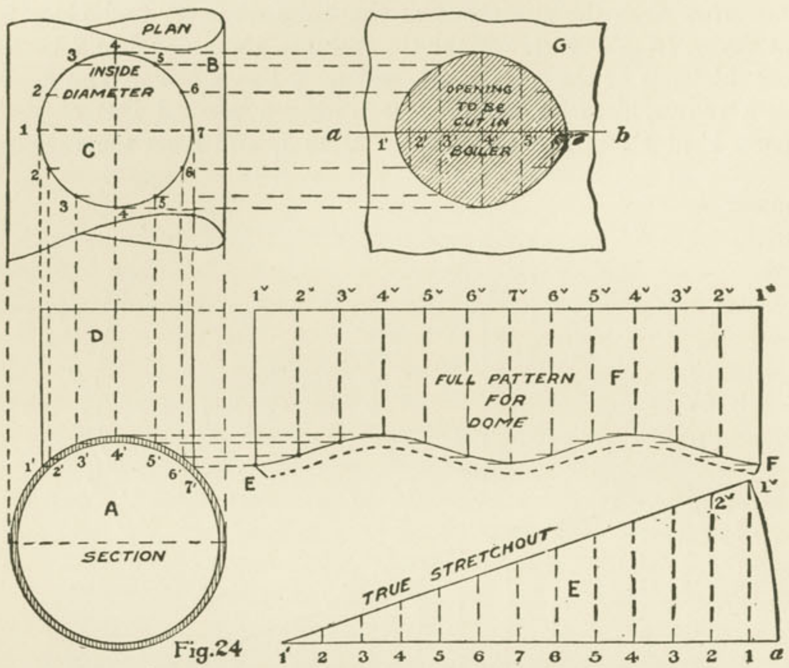


Fig.24

Now take the stretchout of C and place it in E on the line 1′—*a*. Take 7 times the thickness of the metal and place it as shown from 1 to *a*. From 1 erect the vertical line $1—1^{v}$, and intersect it by an arc struck from 1′ as a center and 1′—*a* as a radius. Draw a line from 1^{v} to 1′, which becomes the true stretchout when vertical lines are erected from 1—2—3, etc., as partly shown by $1^{v}—2^{v}$. Take the full stretchout from 1^{v} to 1′ in E, and place it as shown by 1^{v} 1^{v} in F, at right-angles to which drop lines and intersect them by horizontal lines, drawn from similar intersections on the outside of section A. A line traced through points thus obtained, as shown by $E—F—1^{v}—1^{v}$ will be the full pattern for the dome.

To obtain the opening to be cut into the boiler, no allowance need be made to this pattern, because the stretchout will be obtained from the outside diameter. Therefore take the stretchout from 1′ to 7′ in A, and place it on the line *a*—*b* in G, which is extended from the center in C, as shown by similar figures on *a*—*b*. Erect vertical lines as shown, which are intersected by horizontal lines drawn from similarly numbered intersections in the profile C, and resulting in the pattern shown by the shaded part in G.

A flange is allowed to the pattern F, as shown by the dotted line.

In Fig. 25 is shown how the pattern is developed for a **gusset sheet** on a locomotive boiler, when the horizontal section of the boiler is less than that of the fire box. A B C shows the side elevation, C^1 showing the inside diameter of the boiler C, and B^1 the inside diameter of the fire box B; *a*—*b* representing the horizontal distance of the gusset sheet. This problem will be developed by triangulation, and the first step is to divide the diameters B^1 and C^1 each into the same number of spaces, as shown from 1 to 7 and 8 to 14. Draw solid and dotted lines as shown, which represent the bases of triangles which will be constructed, whose altitude will equal the horizontal distance shown from *a* to *b* in side elevation. Therefore in any convenient place draw any line as 2″—*b*, upon which place the various distances of the solid and dotted lines contained in the end view, as shown by similar numbers on the line 2″—*b*. For example, to find the true length of 2—13 in the end view, take this distance and place it as shown from 2′ to 13′ in D. At right-angles to 2′—13′ draw 13′—13 equal to *a*—*b* in the side elevation. Draw a line from 13 to 2′ in D, which is the true length required.

In this manner all of the true lengths on solid lines are obtained, the distance *a*—*b* in A being the same altitude for all triangles in D, as shown by *a*—*b*.

In obtaining the true lengths of the dotted lines, part of the solid line diagrams in D can be used as follows: For example, to find the true length of the dotted line 13—3 in the end view, take this distance and place it as shown from 13′ to 3″ in D; as the altitudes of all triangles are similar, draw a line from 13 to 3″, which is the true length of 13—3 in the end view. Obtain all of the triangles on dotted lines in a similar manner. As B^1 and

C^1 represent the inside diameters, diagrams shown by E and F must be constructed, to which the allowance will be made for the thickness of the metal, and which will give the true girth used in developing the pattern.

Take the stretchout of B^1 and place it on 1—1 in E. Add 1—*e* equal to 7 times the thickness of the metal, and with 1 as a

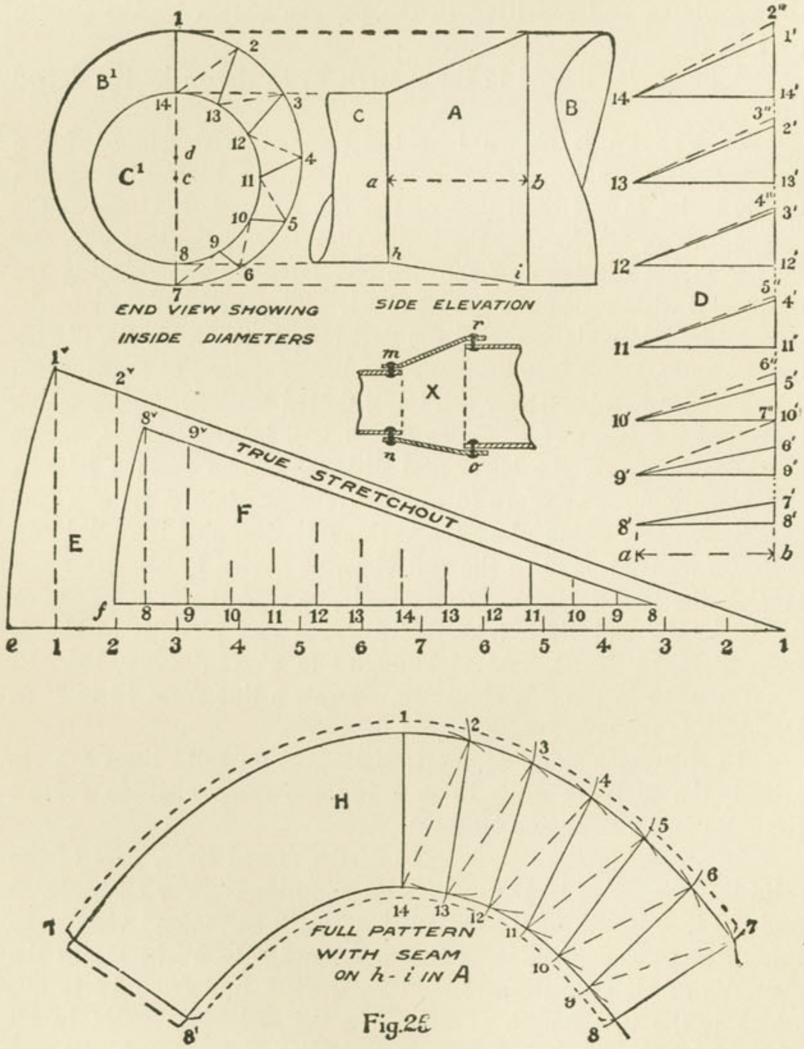


Fig. 25

center, draw the arc *e*—1^v intersecting the vertical line 1—1^v at 1^v. Draw a line from 1^v to 1, and erect a line from 2, obtaining 2^v. Then 1^v—2^v is one of the true divisions. In similar manner place the stretchout of C^1 on the line 8—*f* in F and in precisely the same manner as in E, obtain one of the true divisions in F, shown by 8^v—9^v. Having all of the true lengths, the pattern is obtained as shown in H with a seam along *h*—*i* in A. Take the distance of 1′—14 in D, and place it as shown by 1—14 in H. With 1 as a center and 1^v—2^v in E as a radius describe the arc 2 in H, and intersect it by an arc struck from 14 as center and 14—2″ in D as radius.

Now with 8^v—9^v in F as a radius and 14 in H as a center describe the arc 13, and intersect it by an arc struck from 2 for a center, and 2′—13 in D as a radius.

Proceed in this manner, using alternately, first the division equal to 1^v—2^v in E, then the proper dotted line in D; the division equal to 8^v—9^v in F, then the proper solid slant line in D until 8—7 in the pattern has been obtained. Then 1—7—8—14 in H is the half pattern.

If the whole pattern were desired, trace opposite the line 1—14, as shown by 7′—8′. After the entire pattern has been laid out, laps are allowed as shown by the dotted curved lines, for flanging and riveting, as shown in diagram X, by *m*—*n* and *o*—*r*.

When **large spheres** are hammered from heavy or light copper, or any other material, they are usually made from horizontal sections or "zones," as shown in Fig. 26, and their patterns are simply frustums of cones, and are developed by the radial line method as follows: Draw the circle of the required size using E as center. Through E draw the vertical center line E F. Divide the semicircle into seven equal spaces as shown, or as many as are required. Draw the horizontal planes or seam lines as shown by 1—1′, *a*—*a*′, *b*—11 and *c*—*c*′.

Now draw lines through the points 1 to *a*, *a* to *b* and *b* to *c* intersecting the center line E F at F, G and D respectively, which represents the center points from which the patterns will be struck.

The quarter-section on the plane 1′—1 is shown by H, while the quarter-section on the plane *b*—11 is shown by J. Divide both these quarter-sections into equal parts as shown from 1 to 6 in H and 7 to 11 in J. How the stretchout of these sections will be placed upon the patterns will be explained as we proceed.

For the half pattern for the "zone" A, use F as center and with radii equal to F—*a* and F—1, describe the arcs 1—1″ and *a*—*a*′. As H represents the quarter-section on the plane 1—1′, and as the arc 1—1″ is struck from this plane line, place twice the amount of spaces in 1—6 upon the arc 1—1″ as shown, and draw a line from 1″ to F, cutting the inside arc at *a*′. *a*—1—1″—*a*′ is then the half pattern desired. Now with G as a center, and radii equal to G *b* and G *a*, draw the arcs *b*—7 and *a*—*a*″.

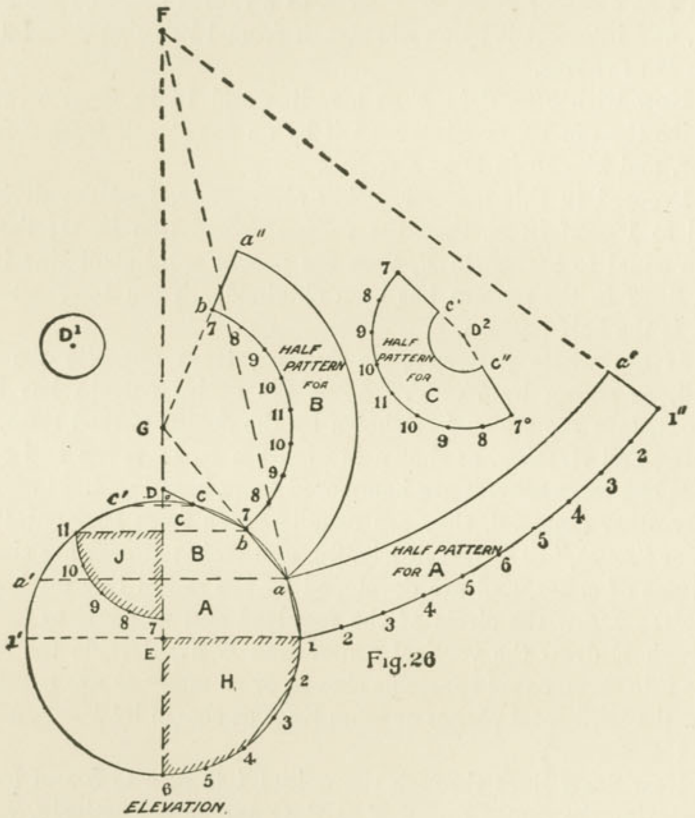


Fig.26

As J represents the quarter-section on the plane *b*—11 and as the arc *b*—7 is struck from this plane line, then place twice the number of spaces in J upon the arc *b*—7 as shown, and draw a radial line from G through 7 until it intersects the outer arc at *a*″. *a*″—*a*—*b*—7 is then the half pattern for "zone" B.

Now with radii equal to D—*c* and D—*b* and using D^2 as center, describe the arcs *c*′—*c*″ and 7—7°. Draw a line from 7

to D^2 cutting the inner arc at *c*′. On the arc 7—7°, which represents the plane line on *b*—11 in elevation, place twice the stretch-out of the quarter-section J, as shown in the half pattern for C. From 7° draw a line to D^2 cutting the inner arc at *c*″. The full pattern for the last zone D is shown by D^1, which is struck by a radius equal to *o c* in elevation. Laps should be added to the pattern for flanging and joining.

When **large copper kettles** are to be hammered from heavy sheet copper, no matter what shape or size they may have, the principles to be employed are those shown in connection with Fig. 27, in which a full section of a kettle is shown; although in

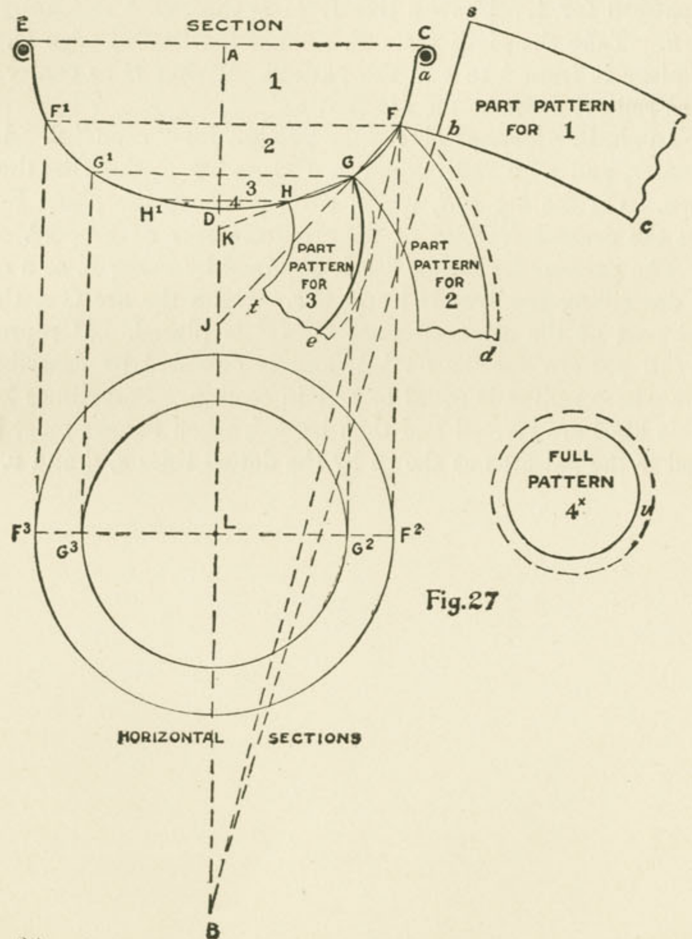
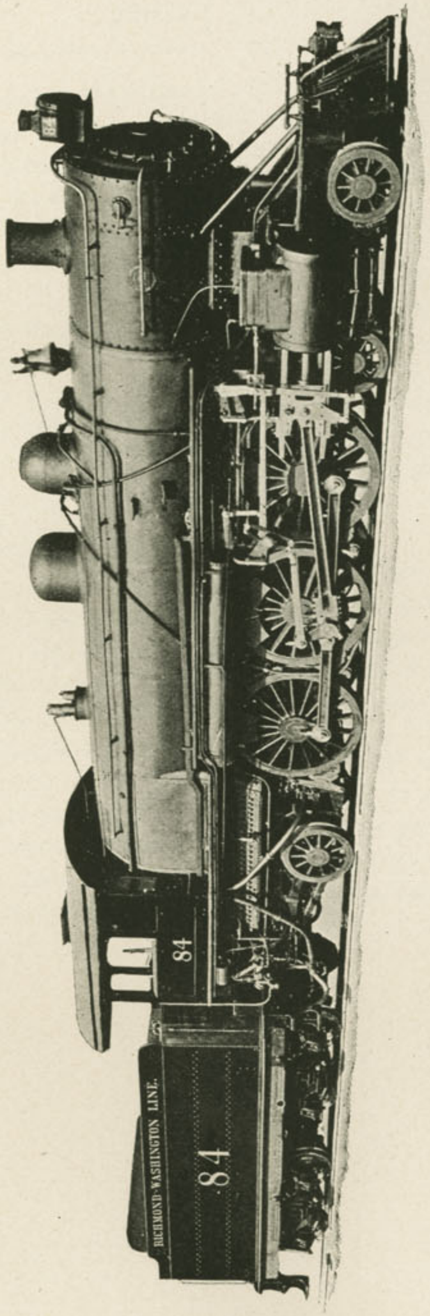


Fig.27

practice one half-section is all that is required. First draw the center line A—B and complete the section of the kettle shown by C D E. Divide the half-section C D into as many spaces as desired, as shown by F G and H. From these points draw horizontal lines F—F^1, G—G^1 and H^1—H. On the planes F—F^1 and G—G^1 draw the horizontal sections F^2—F^3 and G^2—G^3. Draw lines through C F, F G, and G H, intersecting the center line A B at B, J, and K respectively. For the pattern for "zone" 1 use B as a center and B F as a radius, and describe the arc *b c*. Assuming that "zone 1 is to be constructed in six parts, then place on the arc *b c* one-sixth of the circumference of F^2—F^3, as partly shown in the pattern for 1. Draw a line from B through *b* indefinitely as shown. Take the girth from F, around the beaded edge C, to *a*, and place it from *b* to *s* in the pattern. Using B as center with B *s* as radius, describe the arc shown.

In similar manner obtain the pattern for "zone" 2. Use J as center, and with radii equal to J G and J F, describe the arcs shown. On the arc F *d*, which corresponds to the plane F—F^1, place the desired fraction of the circumference of F^2—F^3.

The pattern for "zone" 3 is obtained by using K as a center and describing the arcs H *t* and G *e*. Upon the arc G e, the desired part of the circumference G^2 G^3 is placed. 4^x represents the full pattern for "zone" 4, and is obtained by describing a circle whose radius is equal to DH in section. Sometimes kettles of this kind are riveted and then brazed, when flanges must be allowed to the patterns as shown by the dotted lines *e, d* and *v*.



PACIFIC TYPE LOCOMOTIVE FOR HEAVY PASSENGER SERVICE USED ON THE RICHMOND, FREDERICKSBURG & POTOMAC R. R.
(Baldwin Locomotive Works)

Light Sheet Metal Work.

When sheet metal of number 20 gauge and lighter is used, no allowance is made for the thickness of the metal, when developing the patterns; and, as we assume that the metal has no thickness, we use the net patterns. In the problems which will follow, the patterns will be developed for articles such as are used in sheet-metal working shops.

The first problem is that of **pieced elbows**, three styles of which are shown in Figs. 28, 29 and 30. All of the elbows shown are to have 90° when completed. The first shows a

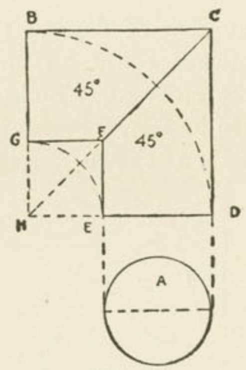


Fig. 28

two-pieced elbow whose section or profile is round, as indicated by A. It will be noticed that both arms are equal, as shown by B C F G and C F E D, each being equal to 45° on the line C H.

Fig. 29 shows a three-pieced elbow whose section A is square. In this case the end pieces B J F E and H G D C have one-half the number of degrees shown by J H G F. Thus the end pieces have each $22\frac{1}{2}$°, and the middle piece 45°, making a total of 90°.

In Fig. 30 we have a four-pieced elbow whose section A is an ellipse. In this case M G F C and K D E J contain one-half of K L H J or L H G M. Thus the end pieces contain each 15°, and each of the middle pieces 30°. From the above the following rule is established:

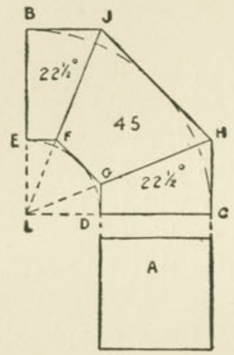


Fig. 29

No matter what number of degrees the finished elbow will have the end pieces always count one and the middle pieces count two. In the three elbows shown in Figs. 28, 29 and 30, the finished elbows are to be 90°. Following the above rule Fig. 28 has two ends, $\frac{90}{2}=45°$, as shown. Fig. 29 has 2 ends and 1

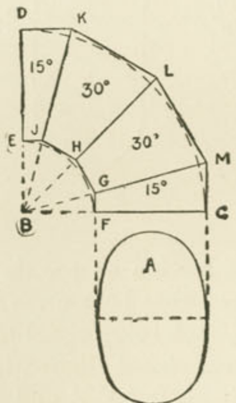


Fig. 30

middle piece; then 1+2+1=4; $\frac{90}{4}=22\frac{1}{2}°$, as shown. Fig. 30 has 2 end pieces and 2 middle pieces, 1+2+2+1=6; $\frac{90}{6}$ =

15°, as shown. H E in Fig. 28, L D in Fig. 29 and B F in Fig. 30 are called the *throats.*

In obtaining the patterns for any number of pieces in elbow work, no matter what the degree may be when finished, it is not necessary to draw the completed elevation, as shown in Figs. 28, 29 and 30. All that is required is to find the degree of the first miter line, as above described, by using a protractor, as shown in Fig. 31.

The elbow shown in Fig. 30 will be developed first. As the rise of the first miter line equals 15°, then, from the center *a* in the protractor (A in Fig. 31), draw a line through the 15th degree, extending it indefinitely as shown. On the line *a*-9 establish the throat *a*-1, also the minor axis of the ellipse, as shown by 1-9. From 1 and 9 erect vertical lines intersecting the 15th degree line at 1′ and 9′. If the ellipse were reversed, with the major axis on 1-9, the pattern would be developed the same as will follow:

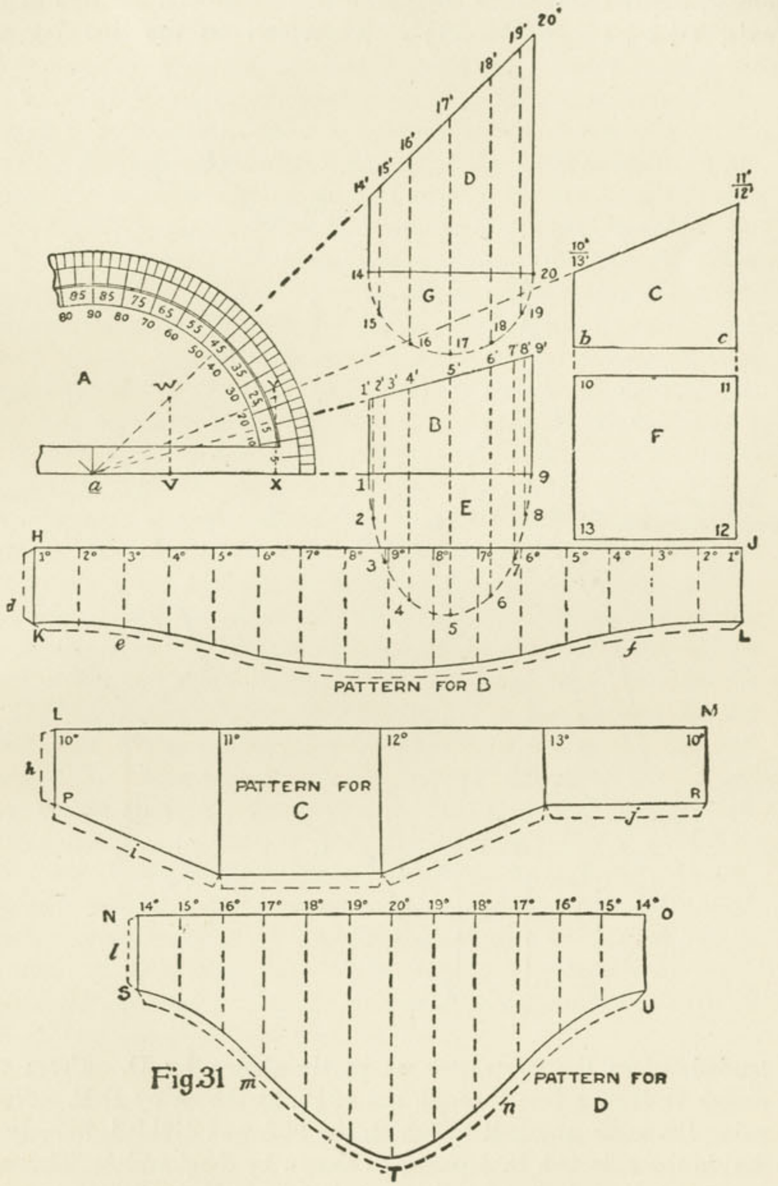
Divide the semi-ellipse E, which has been placed on 1-9, into equal spaces by 1-2-3 to 9, as shown. From these points erect vertical lines intersecting the miter line from 1′ to 9′. Now take twice the stretchout of E and place it on the horizontal line H J, as shown by similar figures 1° to 8°. From these points drop vertical lines indefinitely. Now, measuring from the line 1-9 in B, take the various distances to points 1′ to 9′ and place them on similarly numbered lines in the pattern for B, measuring in each instance from the line H J. Trace a line through the points thus obtained, as shown by K L. Then H J L K will be the pattern for the end piece B, *d-e-f* showing the laps. For the pattern for the middle sections or pieces shown in Fig. 30, it is only necessary to trace the pattern H J L K, in Fig. 31, opposite the line H J, which will be the desired pattern

The pattern for the three-pieced elbow, shown in Fig. 29, requires 22½° for the miter line. Therefore, from *a*, in Fig. 31, draw a line through 22½° indefinitely as shown. Let *a*-X represent the throat of the three-pieced elbow. From X erect the vertical line, cutting the angle of 22½° at Y. Then Y X is the length of the end piece on the throat side, and one-half the length of the middle pieces. At pleasure establish the point 13′, from which draw the vertical line 13′-*b* equal to Y X. Draw the horizontal line *b c* equal to the width of the square pipe, and from *c* erect a line cutting the miter line at 12′. Below *b c* draw the section F of the square pipe (or rectangular pipe, whichever it may be), and number the corners from 10 to 13. Now take a stretchout of the section F and place it on the line L M, as shown from 10° to 10°. Perpendicular lines are drawn from these points, as shown, and made equal in length, measuring from the line L M to similarly numbered lines in C, measuring from the line *b-c*. A line traced through the points thus obtained in the pattern for C, as shown from P to R, will be the pattern for the end piece. For the middle piece simply trace M R P L opposite the line L M. *h-i-j* shows the laps for soldering or seaming.

A 45° miter line is required for the two-pieced elbow in Fig. 28. Therefore, in Fig. 31, draw a line from *a* through the 45th degree indefinitely as shown. Assume that the throat of this elbow is to be equal to *a*-V. Then from V erect the vertical line V-W, cutting the 45th degree line at W. Take this distance W V and place it vertically from 14′ to 14 in D. Draw the diameter 14-20, and erect 20-20′ until it cuts the miter line at 20′. Place the half-section of the round pipe on the line 14-20 as shown by G, and divide it into equal spaces, as shown from 14 to 20, from which erect vertical lines cutting the miter line from 14′ to 20′ as shown.

Take a stretchout of twice the semi-circle G and place it on the horizontal line N O, as shown by similar figures, from which drop perpendiculars as shown. Now, measuring from the line 14-20 in D, take the various distances to points on the miter line and place them on similarly numbered lines in the pattern for D, measuring from the line N O, and resulting in the miter cut S T U, when a line is traced through these points. N S T U O is then the desired pattern. *l-m-n* represents the laps for joining.

In Fig. 32 is shown how tapering pieced elbows are developed. The developments are shown for a three-pieced elbow, whose top and bottom diameters are given. This method can be applied to any size or number of pieces, when the rise and projection are not specified; but where these measurements are given, this method of development could not be employed, and the triangulation method, explained in connection with a ship's ventilator in a following problem, must be used. Let B-C-7-1 be the elevation of the frustum of a right cone, from which a three-pieced, tapering elbow is to be cut, 1-7 representing the diameter at the bottom and B-C the diameter at the top. Now, using the same rule for finding the degree of the miter line, as was ex-



plained in connection with elbow work, we have in a three-pieced elbow, whose angle when completed will be 90° on the line of its axis, $1+2+1=4$; $\frac{90}{4}=22\frac{1}{2}°$. Therefore, on the line 7-1 ex-

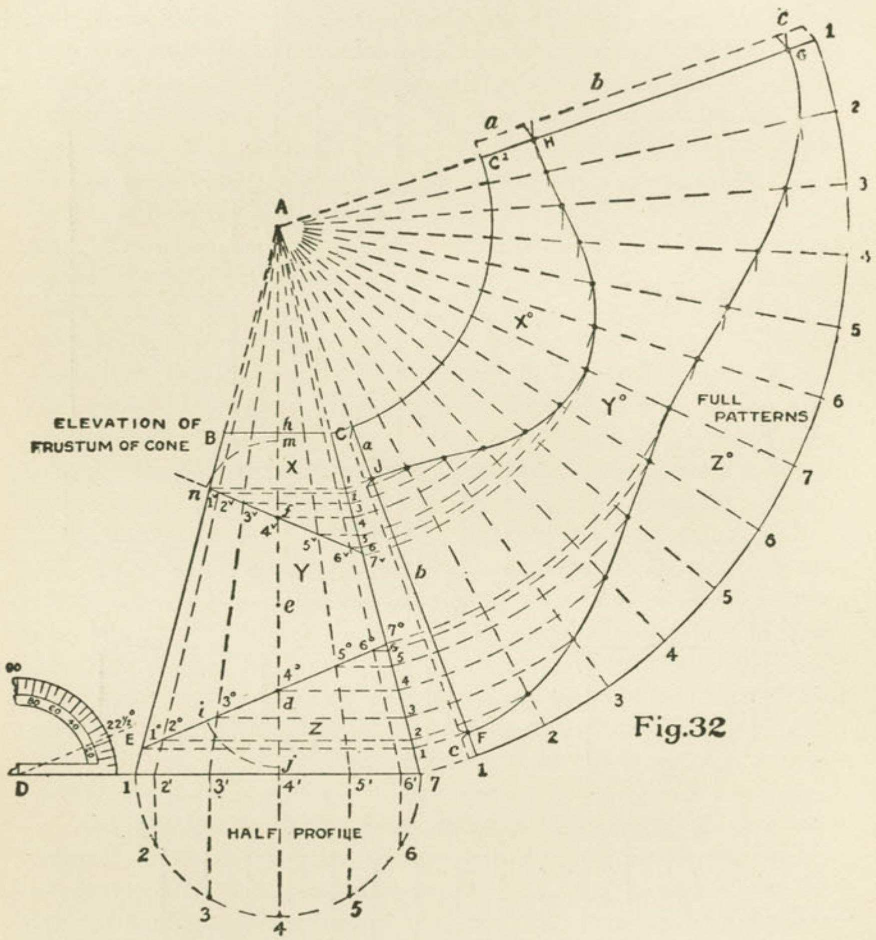


Fig. 32

tended, place the protractor as partly shown by D. From the center D draw a line through the $22\frac{1}{2}°$, as shown by D-E. Now, using the same numeral by which the 90° was divided, namely 4, divide the axis 4′-*h* in 4 parts, as shown by *d-e-f* and *h*. Through the first point *d*, draw a line parallel to D E until it intersects the sides of the cone at 1° and 7° as shown.

It is now necessary to place this same angle through the point *f*, but in an opposite direction. This is done as follows:

With *d* as center describe the arc *i-j*. With the same radius, and *f* as center, draw the arc *m-n*, making the distance from *m* to *n* equal to the distance shown from *j* to *i*. From *n* draw a line through *f*, extending it until it meets the side of the cone at 1^v and 7^v. Having these miter lines in position, the pattern is developed the same as any intersected cone. Place the half-profile on the line 1-7, as shown, which divide into equal spaces from 1 to 7. From these points erect vertical lines cutting the base line at 1, 2′, 3′, 4′, 5′, 6′ and 7, from which points radial lines are drawn to the apex A, cutting the miter lines from 1° to 7° and from 1^v to 7^v. At right-angles to the axis A-4′, from the various intersections on 1°-7° and 1^v-7^v, lines are drawn intersecting the side of the cone C-7, from 7 to 7° and from 7^v to 1 respectively.

For the pattern use A as a center, and, with A-7 as a radius, describe the arc 1-1, upon which place the stretchout of double the number of spaces contained in the half-profile, as shown by similar figures on the arc 1-1. From these small figures draw radial lines to A, and intersect them by arcs struck from A as a center, with radii equal to similar points of intersections on the side of the cone C-7, thus resulting in the points of intersections shown in the pattern. Now, with radius equal to A C, draw the arc C-C^1 as shown. Then 1-G-F-1 or Z° is the pattern for Z; G H J F or Y° the pattern for Y, and H-J-C-C^1 or X° the pattern for X. *a-b-c* shows the lap allowed for riveting. Laps must also be allowed along the miter lines H-J and F-G to allow the seaming of the joints, as shown by *a-b* and *c-d* in Fig. 33.

When the patterns in Fig. 32 are rolled up and put together, the elbow will have the appearance shown in Fig. 33. Note that *e-f-h* is a right-angle, X, Y and Z being similar to X,Y and Z in Fig. 32. It is evident that while Fig. 33 can be drawn from dimensions obtained in Fig. 32, it would be impossible to draw it without first knowing these dimensions.

In Fig. 34 is shown how the patterns are obtained for **T-joints** when the diameters of both cylinders are equal. A is the profile of the vertical cylinder, and B the profile of the horizontal cylinder. Divide the profiles A and B each into the same number of spaces, as shown by 1, 2, 3, 4 and 5, and *a, b, c, b, a,* respectively. Drop vertical lines from A and draw horizontal lines from B.

intersecting each other in elevation, as shown. Draw the miter or joint lines C D E.

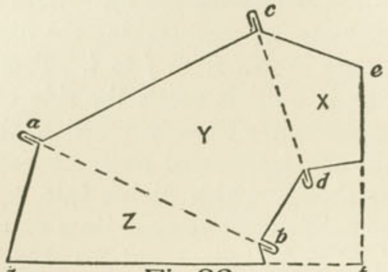


Fig.33

For the pattern for the vertical cylinder take the stretchout of the profile A and place it on the horizontal line 1′-1′, as shown. At right-angles to this line and from the various intersections, draw lines and intersect them by horizontal lines drawn from the intersection on C D E, and resulting in the full pattern for the

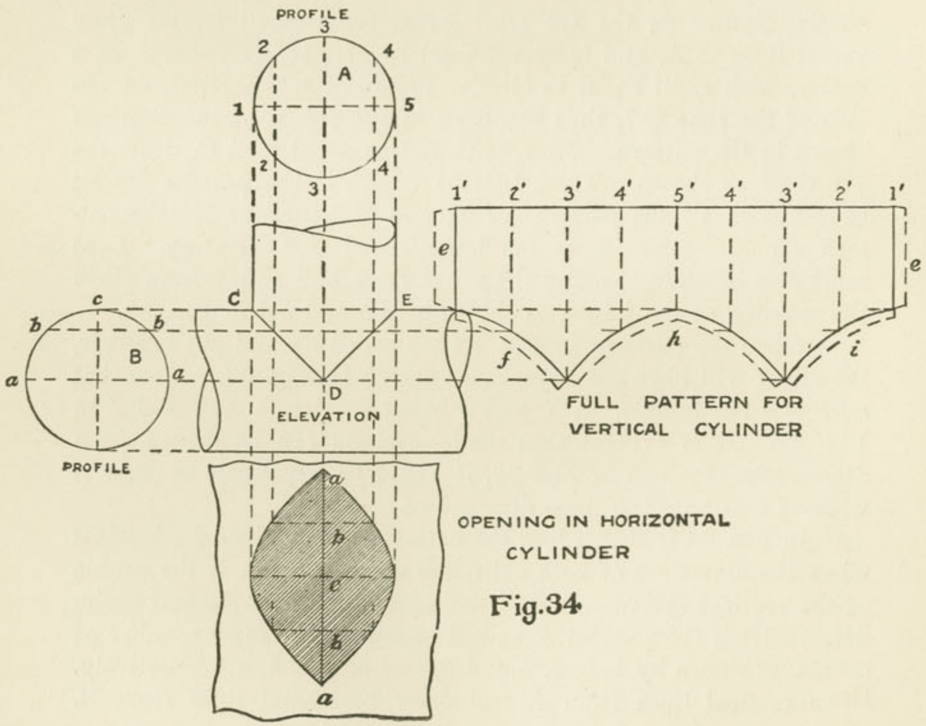


Fig.34

vertical cylinder shown. *e-f-h-i-e* shows the lap allowed for riveting or joining. For the opening to be cut into the horizontal cylinder, take the stretchout of *a-b-c-b-a* and place it on the

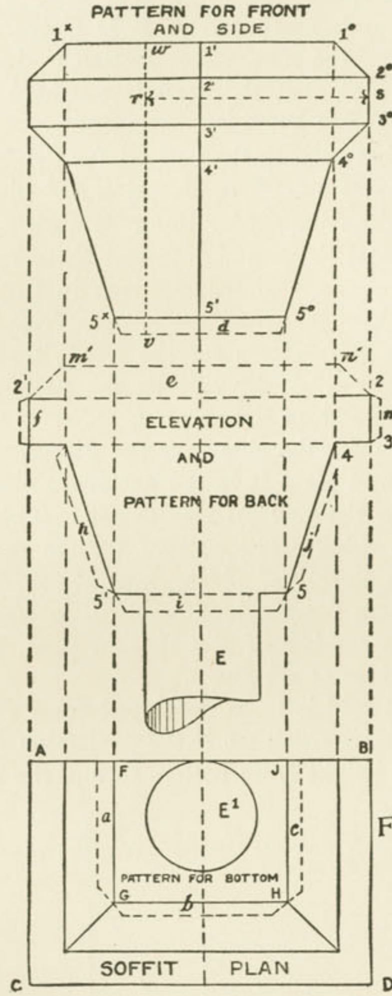


Fig.35

center line 3-D extended, as shown from *a* to *a*. Through *a b c b a* draw horizontal lines and intersect them by vertical lines dropped from the intersections on the miter line C D E. A line traced through these points, as shown by the shaded part, will be the desired opening.

In Fig. 35 is shown how the patterns are developed for a **leader or conductor head.** These heads are placed upon the top of rain water conductors to receive the water from any part of a roof by means of a connecting tube. Let 2-5-5′-2′ represent the elevations of the leader head, and A B D C the soffit plan. E shows the elevation of the tube, whose section is shown by E^1. It will be noticed in plan that the head is moulded on three sides with a flat back, as shown by A-B.

The first step is to obtain the pattern for the front, for which take the stretchout of 1-2-3-4-5 in elevation and place it as shown by 1′-2′-3′-4′ and 5′ on the center line extended. Through these points draw horizontal lines, and intersect them by vertical lines drawn from similar points of intersections in the elevation, and giving the intersections shown in the pattern from 1° to 5°. 1′-1°-5°-5′ is then the half-pattern for the front; trace this half opposite 1′-5′. Then 1^x-1°-5°-5^x will be the pattern for the full front. A lap is allowed as shown at *d*.

For the pattern for the side take the distance from B to D, or C to A in plan, and place it in the pattern, as shown from *s* to *r*. Through *r* draw the vertical line shown. Then *w*-1°-5°-*v* is the pattern for the sides. The pattern for the back is simply a reproduction of the elevation, adding laps at *m′-n′-e* and *m, j, i, h, f*. For the pattern for the bottom piece, to which the tube E is connected, take a tracing of F-J-H-G in plan, with the circle E^1 cut out, adding laps at *a-b* and *c*.

When an **offset boot** is to be developed from round to round, as shown in Fig. 36, in which *a-b* is the projection from outside to outside, and *b-c* the height from bottom to top, the rule to be used

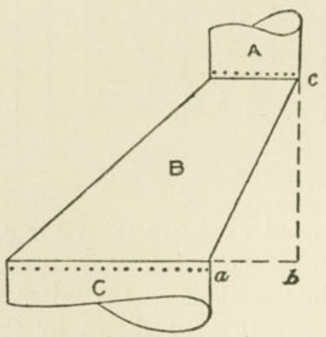


Fig.36

is the same as that in developing an oblique or scalene cone, and is explained in detail in connection with Fig. 37. Let B represent the elevation of the offset, whose vertical height is equal to *c b*, and whose projection from out to out is equal to *a-b*. Let 1-7 represent the lower diameter, and 1°-7° the upper diameter.

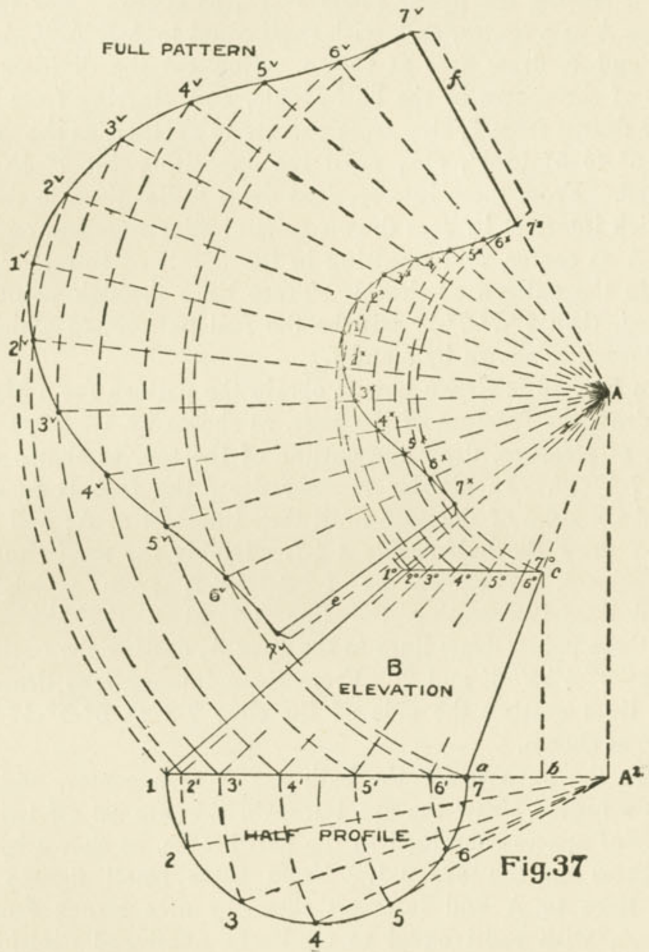


Fig.37

Extend the sides of the cone until they intersect each other at A. On the base line 1-7 place the half-profile of the large pipe as shown. Divide this into equal spaces, as shown from 1 to 7, from which points draw lines to the apex A^1 in plan, which is obtained by dropping a vertical line from A to the line 1-7 extended. These lines then represent the bases of triangles whose altitudes are equal to A^1-A.

Therefore, with A^1 as a center, and radii equal to the various points in the half-profile, strike arcs cutting the base line 1-7 from 2′ to 6′, as shown. From these points draw lines to the apex A, cutting the upper plane 1°-7°, as shown. For the pattern use A as a center, and, with radii equal to A-1, A-2′, A-3′, 4′, 5′, 6′ and 7, draw arcs as shown. Now set the dividers equal to one of the spaces in the half-profile, and, starting from 7^v, on the arc drawn from 7, step from one arc to another, as shown from 7^v to 6^v to 5^v to 4^v, etc., until the opposite point 7^v has been obtained. From these intersections draw radial lines to the apex A, which intersect by arcs drawn from similar numbers on 1°-7°, using A as center, and resulting in the points of intersections 7^x to 7^x in the pattern as shown. Trace lines through points thus obtained, then 7^x-7^v-7^v-7^x will be the full pattern, to which laps are allowed, as shown by *e* and *f*.

In Fig. 38 is shown how to obtain the pattern for a **hip bath.** First draw the frustum of the cone, as shown by 1-7-8-9, through which, at pleasure, draw the outline of the top, as shown by the curve 7-4″-1″. In similar manner draw the foot B as shown. Extend the sides of the cone until they intersect at A; and on the line 1-7 draw the half-profile 1-4-7. Divide the semi-circle into equal spaces, as shown by 1-2-3-4-5-6-7, from which draw vertical lines intersecting the line 1-7 at 2′-3′-4′-5′-6′ and 7. From these points draw lines to the apex A, cutting the curve 1″-7 at 1″-2″-3″-4″-5″-6′ and 7. From these intersections draw horizontal lines cutting the side of the cone 7-8 at 6°-5°-4°-3°-2° and 1° as shown.

For the pattern for the bath use A as a center, and, with A-7 as a radius, draw the arc 1-1. On this arc set off twice the number of spaces contained in the half-profile, as shown by similar figures on the arc 1-1. From these small figures draw radial lines to A and intersect them by arcs struck from the center A, with radii equal to similarly numbered divisions on 7-8. Thus the arc struck with A-4° as a radius intersects the radial line 4-A, and 4-A at Y and Z. Trace a line through the points thus obtained, as shown from C to F. Now, with A-8 as radius, strike the arc D E, as shown, intersecting the radial lines C A and A F at D and E respectively. C D E F 7 is

then the full pattern for the body of the bath, with laps allowed at *b, c* and *d.*

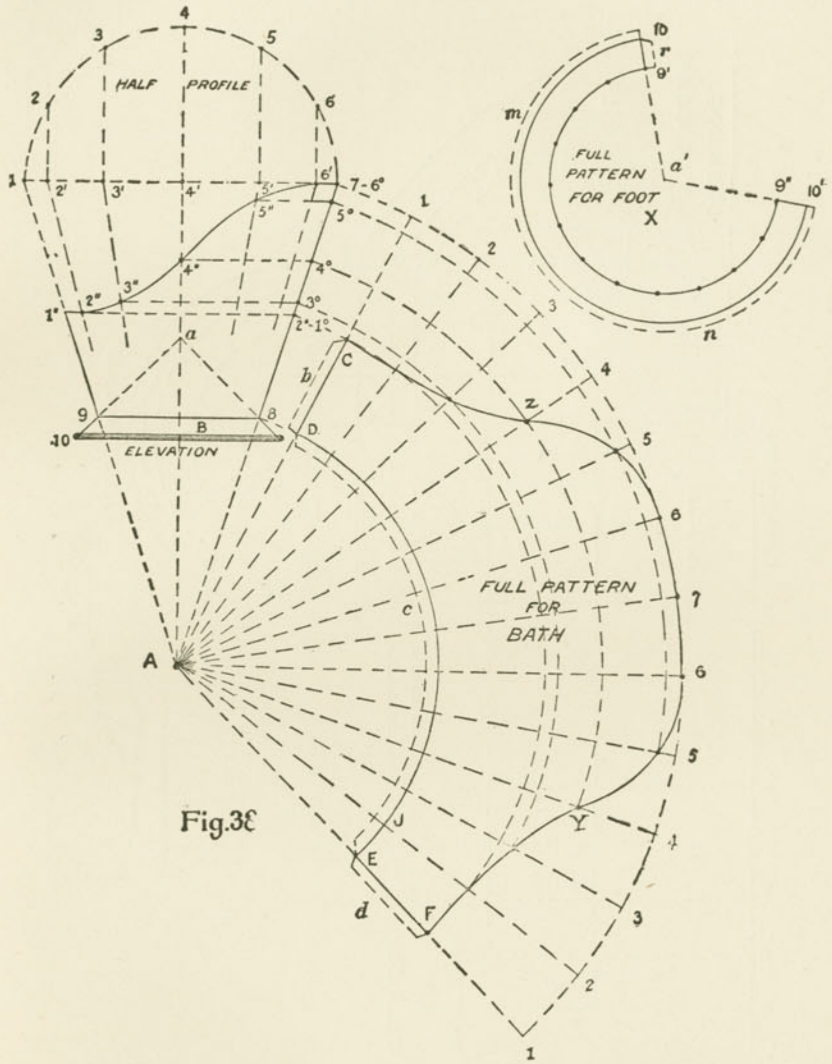


Fig.38

For the pattern for the foot, extend the sides of the foot until they intersect at *a*. Now, with radii equal to *a*-9 and *a*-10, and with *a′* in diagram X as a center, describe the arcs 9′-9″ and 10′-10″. On the inner arc set off as many spaces as are contained in the curve D E, in length equal to J E in the pattern for the bath, and draw radial lines in diagram X, from a' through $9'$ and $9''$ cutting the outer arc at $10'$ and $10''$ respectively, which com-

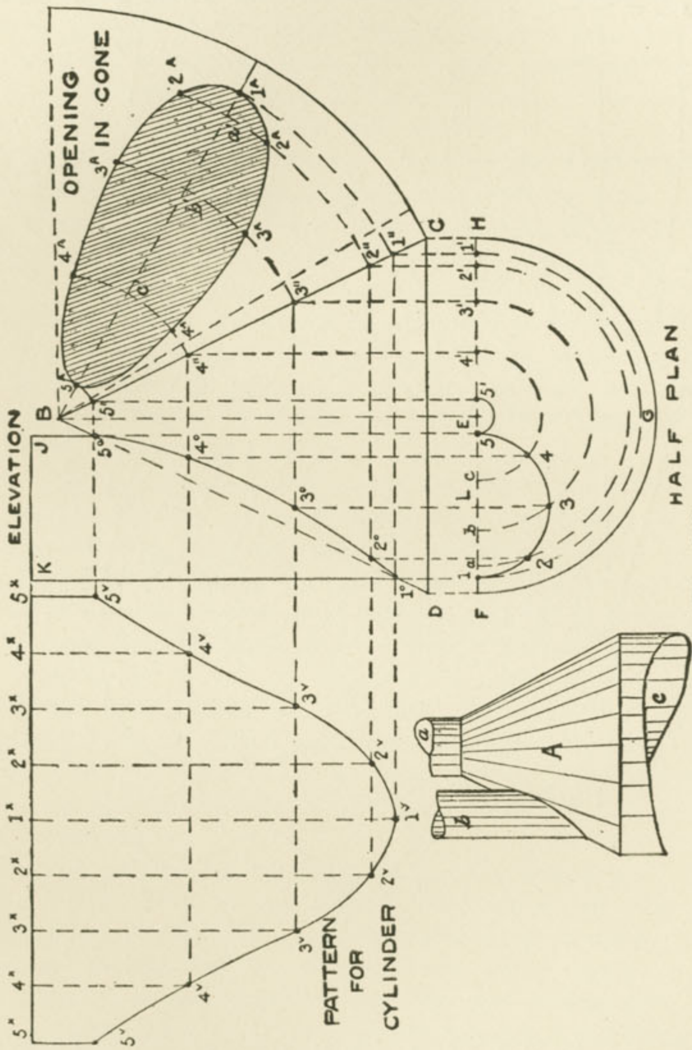


Fig. 39

pletes the pattern for the foot, to which edges are allowed for wiring and seaming, as shown by the dotted lines, *r-m-n*.

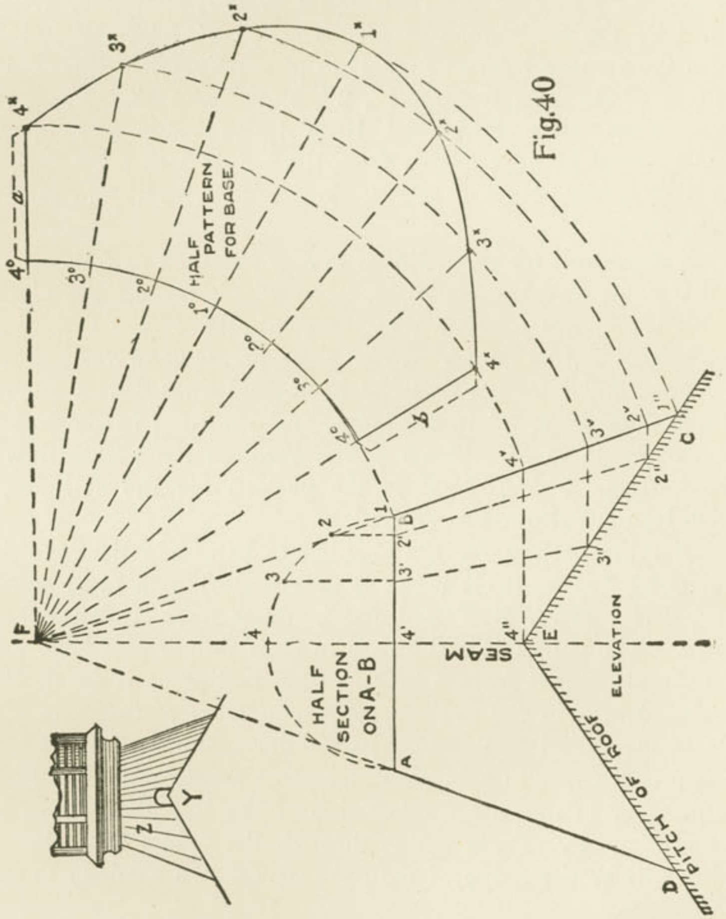
Diagram A, in Fig. 39, shows a **fitting with three outlets** *a, b* and *c* joining the cone A. Before obtaining the pattern, the

intersection line, shown in elevation by $1°$-$5°$, must be obtained. Draw the elevation of the right cone B C D, and, directly below it, the half-plan on D C, as shown by F G H. At pleasure locate the position of the cylinder, as shown by the half-plan 1-3-5, struck from L as center. From 1 and 5 erect vertical lines into the elevation, as shown from $1°$ to K and J to $5°$. Now divide the half-profile of the cylinder in plan, as shown by 1-2-3-4 and 5. With E as a center, and radii equal to E-1, E-2, E-3, E-4 and E-5, draw the semi-circles or planes 1-$1'$, a-$2'$, b-$3'$, c-$4'$ and 5-$5'$. From the various intersections $1'$ to $5'$ erect vertical lines cutting the side of the cone B C at $1''$, $2''$, $3''$, $4''$ and $5''$. From these intersections draw horizontal lines indefinitely, and intersect them by vertical lines drawn from the points 1 to 5 in plan, and resulting in the points of intersections $1°$-$2°$-$3°$-$4°$-$5°$ in elevation as shown.

The pattern for the cylinder is now obtained as follows: Extend J K in elevation as 5^x-5^x, upon which lay off the girth of double the spaces contained in the semi-plan of the cylinder, as shown from 5^x to 1^x to 5^x. From these points draw vertical lines, as shown, and intersect them by horizontal lines drawn from the intersections $1°$ to $5°$ in elevation, and resulting in the intersections 5^v to 1^v to 5^v. Trace a line through the points thus obtained, then 5^x-5^v-1^v-5^v-5^x is the pattern for the cylinder, to which laps are allowed as desired.

For the pattern for the opening to be cut in the cone draw any radial line as B-1^A; using B as a center, with radii equal to B-$5''$, B-$4''$, B-$3''$, B-$2''$ and B-$1''$, draw arcs indefinitely as shown. The points 1^A and 5^A are in their proper positions. Now take the stretchout from a to 2 in plan and place it on similarly numbered arcs in the pattern, as shown from a' to 2^A on either side of the radial line B-1^A. In similar manner take the girths from b to 3 and c to 4 in plan and place them on similar arcs in the pattern, as shown on either side of the line B-1^A, from b' to 3^A and c' to 4^A. Trace a line through the points thus obtained, which will be the shape of the opening (shown shaded) to be cut in the cone.

When a **tapering base** is placed over a double pitched roof, as shown in diagram Y in Fig. 40, by Z, the pattern is obtained by means of radial lines as follows: Let A B C D represent the elevation of the base, shown by Z in diagram Y, and D E C the pitch of the roof. On the line A B draw the half-section, and divide one-half of it into equal spaces, as shown from 1 to 4. From these points, at right-angles to A-B, draw lines intersecting A B at 2′-3′ and 4′. Now extend the sides of the cone until they intersect each other at F. From F, through the various intersections on A-B, draw lines cutting the roof line E C at 1″, 2″, 3″ and 4″. From these points, at right-angles to F-E, draw lines intersecting the side of the cone B-C at 2^v, 3^v and 4^v.



We shall assume that a seam is to be placed on 4′-4″ in elevation. Therefore, with F as a center, and F-B as a radius, describe the arc 4°-4°, upon which place twice the number of spaces contained in the quarter section 1-4-4′, as shown from 4° to 1° to 4° in the pattern. Through these points, from F, draw radial

lines indefinitely as shown, and intersect them by arcs struck from F as center, with radii equal to F-4^v, F-3^v, F-2^v and F-1″, resulting in the points of intersection in the pattern, shown by 4^x, 3^x, 2^x and 1^x. A line traced through the points thus obtained, as shown by 4°-4^x-1^x-4^x-4°, will be the desired half-pattern with seam on 4′-4″ in elevation. Laps are allowed as shown by *a* and *b*.

Fig. 41 shows (by means of triangulation) how a **straight boot** is developed forming, a transition piece from square to round. These boots are used in heating and ventilating work, but the principles of obtaining their patterns are applicable to any similar form. A B C D shows the elevation of the boot, E F G H the plan on D-C and I J K L the plan on A-B. In developing work of this kind, where both halves of the article are symmetrical, no plan view need be drawn, it being here shown only to make the principle clear. All that is necessary is to draw the elevation, as shown by 1-1-4-4. On 1-1 place the half-profile of the round top, as shown by 1-3-1, and on 4-4 the half-profile of the square base, as shown by 4-5-5-4. Divide the half-profile 1-3-1 into equal spaces, from which vertical lines are drawn intersecting 1-1 at 2′-3′-2′. From these points draw lines to 4 and 4 as shown. These lines then represent the bases of sections which will be constructed, whose altitudes will be equal to the heights in the half-profiles. Thus, take the lengths of 4-1, 4-2′ and 4-3′ in elevation and place them on the horizontal line in M, as shown by similar numbers. From 4 in M erect the perpendicular 4-5 equal to 4-5 in the half-profile. As 1 in the half-profile has no height, draw a line from 5 to 1 in M, which represents the true length of 4-1 in elevation on the finished article. From 2′ and 3′ in M erect the perpendiculars 2′-2 and 3′-3 equal respectively to 2′-2 and 3′-3 in the half-profile. Draw lines from 2 and 3 to 5 in M, which will represent the true lengths of 2′-4 and 3′-4 in elevation.

Knowing these true lengths, the half-pattern is developed as shown in diagram N, in which 5-5 is equal to 5-5 in the half-profile. With a radius equal to 5-3 in M, and 5-5 in N as centers, describe arcs intersecting each other at 3. Draw a line from 5 to 3 to 5. Now, with radii equal to 5-2 and 5-1 in M, and with 5-5 in N as centers, describe short arcs, shown by 2 and 1. Now set the dividers equal to the divisions 3-2 and 2-1 in the half-profile, and, starting from 3 in N, step to arc 2, then to arc 1, on either side as shown, obtaining the intersections 2 and 1. Draw a curved line through 1-2-3-2-1, and a straight line from 1 to 5 on either side. Using 1 in N as a center, with radius equal to 1-4 in elevation, describe the arc 4, and intersect it by an arc

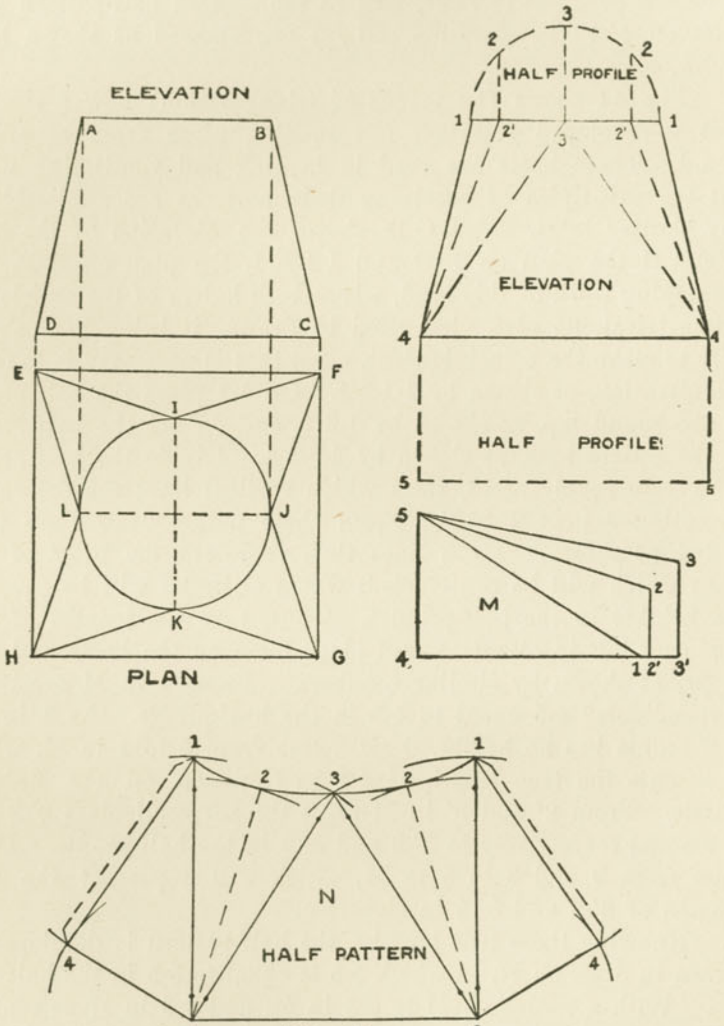


Fig.41

struck from 5 as a center, with a radii equal to 5-4 in the half-profile. Draw lines from 5 to 4 to 1, and allow laps as shown by the dotted lines. 1-4-4-1 then represents the half-pattern.

When a boot is to be developed, as shown in Fig. 42, which is called an **offset boot**, from rectangle to round, in which the halves of the plan are not symmetrical, the round top being placed in the corner of the rectangular base, the method to be employed in finding the true lengths of the various base lines in plan are different from those shown in Fig. 41. In this case, Fig. 42, a plan must be employed from which the base lines can be obtained, and it should be understood that in developing any irregular article where neither half is symmetrical a plan must always be used in a manner similar to that which will be explained in connection with the offset boot.

A B C D represents the plan of the rectangular base, and 1-4-7-10 the plan view of the round top, the elevation being indicated by E F G H, whose vertical height equals *b-c*. Through the center of the circle *a*, in plan, draw the diameters 1-7 and 4-10. Divide the quarter circles into equal parts, as shown by 2-3, 5-6, 8-9 and 11-12. From 1, 2, 3 and 4 draw lines to the corner A; from 4, 5, 6 and 7 draw lines to the corner B; from 7, 8, 9 and 10 draw lines to the corner C, and from 10, 11, 12 and 1 draw lines to the corner D. These lines then represent the bases of the triangles which will be constructed, whose altitudes are equal to *b c* in elevation. Thus to obtain the true lengths of the lines shown in A 1-4 in plan proceed as follows:

Take the various lengths of A 1, A 2, A 3 and A 4 in plan and place them on the horizontal line in J, as shown by A 1′, A 2′, A 3′ and A 4′. From these numbers in J erect vertical lines equal in height to *b c* in elevation, and draw lines from 1, 2, 3 and 4 in J to A. These oblique lines represent the true lengths of similar lines in plan. In similar manner obtain the true lengths of the lines shown in B-4-7, C-7-10 and D-10-1 in plan, as shown respectively in diagrams K, L and M, by similar reference letters and numbers.

We shall assume that the seam is to take place along F E in elevation, shown in plan by 7-*d*, and that the pattern is to be developed in one piece, as shown in N, in which A D is equal to A D in plan. With a radius equal to A 1 in J, and A in N as center, describe the arc 1, which intersect by an arc struck from D as a center and D 1 in L as a radius. Now with radii equal to A 2, A 3 and A 4 in J, and A in N as a center, describe short arcs 2, 3 and 4. Set the dividers equal to the spaces 1 2, 2 3 and 3 4 in plan, and, starting from 1 in N, step to arc 2, 3 and 4, as shown. Draw a line from 4 to A. Using A as a center, describe the arc B with a radius equal to A B in plan. With a radius equal to B 4 in K, and with 4 in N as a center, intersect the arc B as shown. Connect lines from A to B to 4. Now,

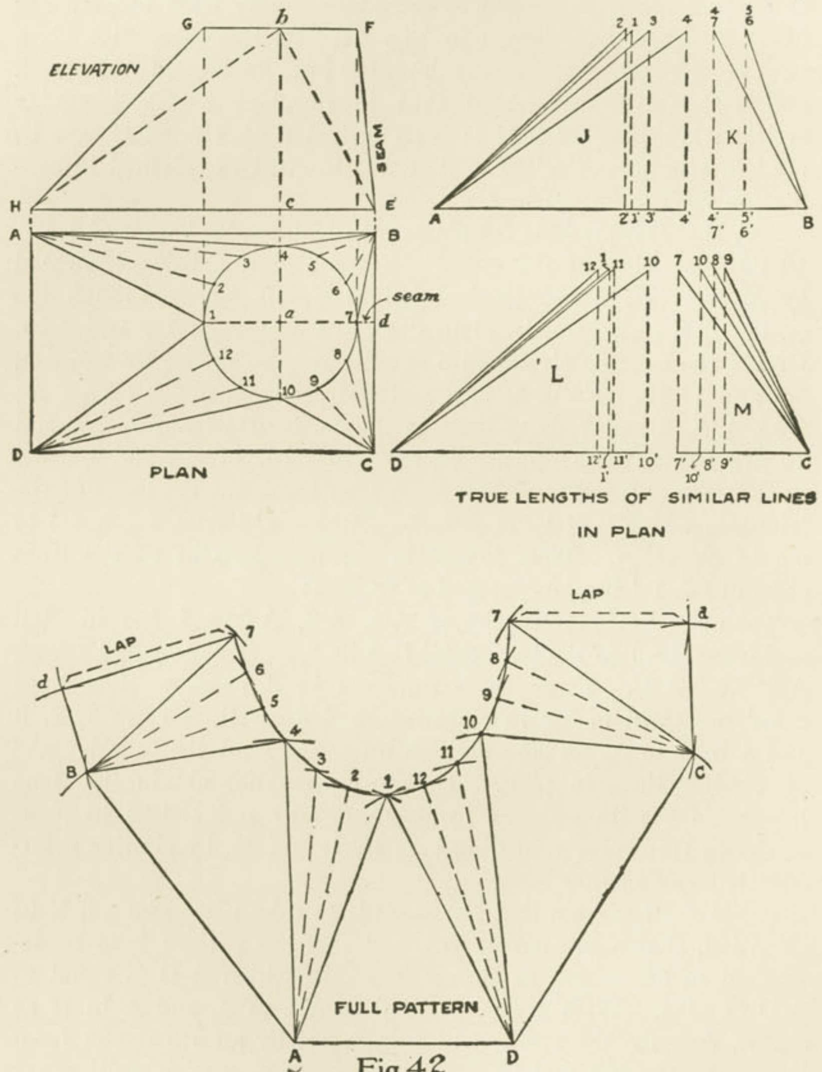


Fig.42

with radii equal to B 5, B 6 and B 7 in K, and with B in N as a center, describe the short arcs 5, 6 and 7. Set the dividers equal to the spaces between 4 and 7 in plan, and, starting from 4 in N,

step to arcs 5, 6 and 7, and draw a line from 7 to B. With B *d* in plan as a radius, and B in N as a center, describe the arc *d*, and intersect it by an arc struck from 7 as a center and E F in elevation as a radius. Draw a line from B to *d* to 7, and allow a lap as shown. Now, with radii equal to D-12, D-11, and D-10 in L, and with D in N as a center, describe short arcs shown by 12-11-10. Set the dividers equal to the various spaces between 1 and 10 in plan, and, starting from 1 in N, step to arc 12, then to 11, then to 10, and draw a line from 10 to D. Using D as center describe the arc C with a radius equal to D C in plan. With a radius equal to C 10 in M, and 10 in N as a center, intersect the arc C as shown. Draw a line from D to C to 10. With radii equal to C-9, C-8 and C-7 in M, and with C in N as a center, describe the arcs 9, 8 and 7. Set the dividers equal to the spaces between 10 and 7 in plan, and, starting from 10 in N, step to arcs 9, 8 and 7, and draw a line from 7 to C. With C as a center describe the arc *d* with a radius equal to C *d* in plan. With F E in elevation as radius, and, with 7 in N as a center, intersect the arc *d* as shown.

Draw a line from 7 to *d* to C, and allow a lap as shown. Through the various intersections 7-6-5-4, etc., draw the curves 7-4-1-10-7, which completes the full-pattern as shown.

If the article were large and the pattern not desired in one but in halves or quarters, the same method would be used as shown in N, cutting the paper pattern along the lines desired, and then transferring to the metal sheet.

When **Y-branches** are constructed which connect two openings to a larger one, as shown in Fig. 43, the patterns are developed by triangulation, as will be described in connection with Fig. 44. In Fig. 43 A-B-C-D-E-F-G-H represents the elevation of a Y-branch whose profile through H F is indicated by J-K-L-M, and whose profiles through A B and D E are shown respectively by S-T-U-V and N-O-P-R. The joint between the two branches takes place on the line C G, through which a true profile must be drawn. This is accomplished as follows:

Knowing that the height is equal to C G, and the distance through G is equal to K M, place one-half of K M on either side of G, as shown by G H and G F, and at pleasure draw a curve through H, C and F, as shown by the shaded profile. As both of the branches are alike it will only be necessary to develop one, as this will answer for both. To avoid a confusion of lines

C-D-E-F-G has been transferred to Fig. 44, as shown by 14-1-7-8-11′. In similar manner take tracings of N-O-P, *a*-L-M and C-G-H, in Fig. 43, and place them as shown respectively by 1-4-7, 11′-8-11 and 14-11′-11°, in Fig. 44. Divide the profile B into as many spaces as are contained in C and D, and number them as shown from 1 to 7. In similar manner number the spaces in C, as shown from 8 to 11, and in D, as shown from 11° to 14. From

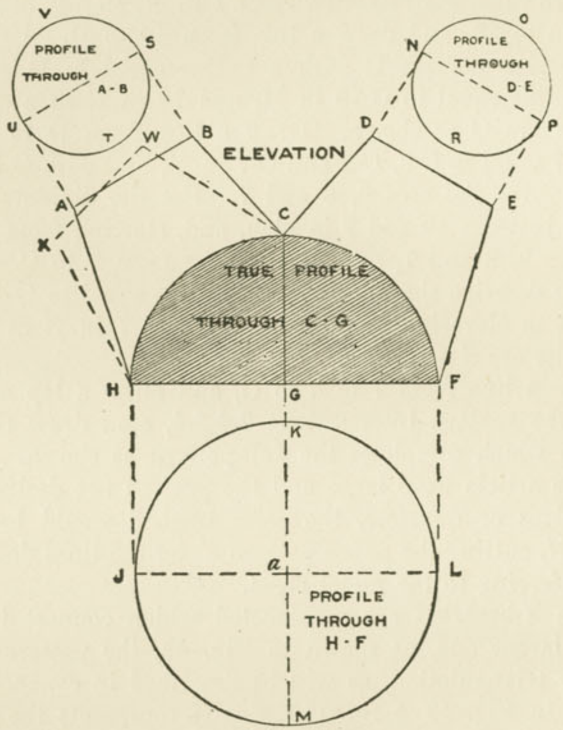


Fig.43

the various divisions in B, and at right-angles to 1-7, draw lines intersecting 1-7 from 2′ to 6′. In similar manner from the divisions in C and D draw lines at right-angles to 8-11′ and 11′-14, intersecting these lines from 9′ to 13′. Draw solid and dotted lines in a manner indicated in A. These solid and dotted lines represent the bases of sections which will be constructed, whose altitudes are equal to the heights in the profile B, C and D.

The oblique lines in diagram E show the true lengths of the solid lines in A, while the oblique lines in diagram F show the true lengths of the dotted lines in A.

For example, to find the true length of the solid line 4′-11′ in A, take this distance and place it on the horizontal line in E, as shown by 4′-11′ From the points 4′ and 11′ erect the prependiculars 4′-4 and 11′-11 equal respectively to 4′-4 in B, and 11′-11 in C, or 11′-11° in D. A line drawn from 4 to 11 in E will give the true length. In this manner all of the solid lines in E are obtained. In precisely the same manner the true lengths of the dotted lines in F are obtained, as shown by similar reference numbers in A-B-C and D.

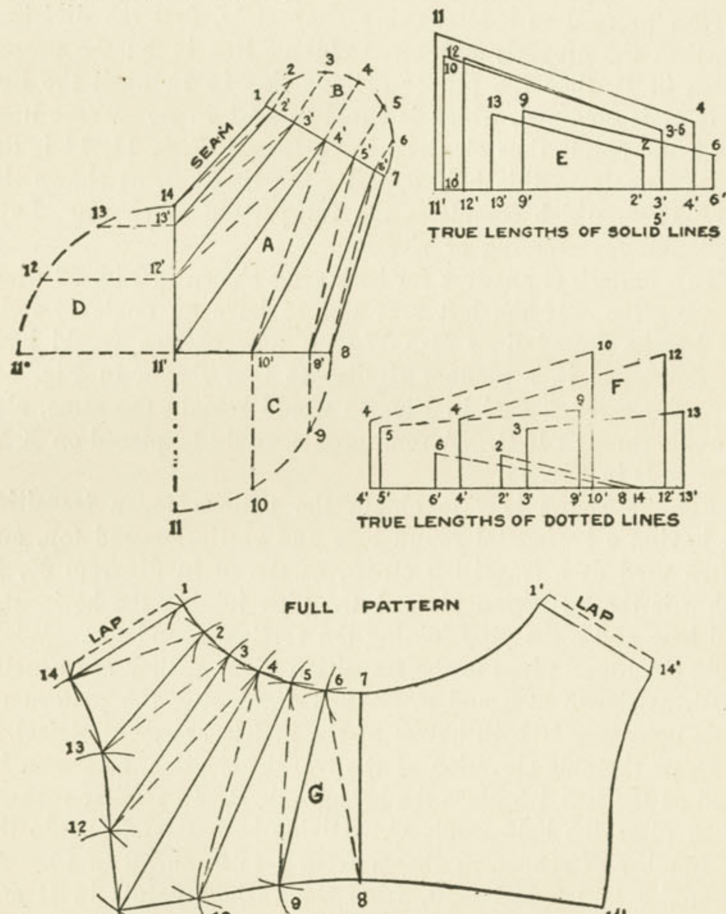


Fig.44

Having obtained all of the true lengths, the pattern G is developed as follows: Assuming that the seam is desired along

1-14 in A, take the distance of 7-8 and place it on the vertical line in G, as shown by 7-8. With 7-6 in B as a radius, and 7 in G as a center, describe the arc 6, and intersect it by an arc struck from 8 as a center and 8-6 in F as a radius. Now, with 8-9 in C as a radius, and 8 in G as a center, draw the arc 9, and intersect it by an arc struck from 6 as a center and 6-9 in E as a radius. Proceed in this manner, using alternately first the divisions in B, then the oblique lines in F; the divisions in C, then the oblique lines in E, until the line 4-11 in G has been obtained.

Now proceed as before, using alternately, first the divisions in D, then the properly numbered oblique line in F; the proper division in B, then the proper oblique line in E, until the line 14-1 in G is obtained, which is equal to 14-1 in A. Trace lines through the points thus obtained in G, then 1, 7, 8, 11, 14 is the half-pattern; trace this half opposite the line 7-8, as shown by 7-1′-14′-11′-8, which completes the full-pattern as shown. Laps are allowed for seaming or riveting.

This pattern G answers for both arms shown in Fig. 43 when they are alike. If the left arm was to have an angle as indicated by the dotted lines H-X-W-C, a new pattern would have to be developed in a manner similar to that shown in Fig. 44. The profile through C-G in Fig. 43 would remain the same, also the profile through H-G. A semi-profile would be placed on X W similar to B in Fig. 44.

Fig. 45 shows how to obtain the pattern for a **transition piece** having a horizontal round base and vertical round top, and is often used as a transition elbow, as shown in diagram X, in which *a* is the transition piece, *b* the pipe joining the horizontal round base and *c* the pipe joining the vertical round top. When joining the round pipes to the transition piece *a,* they are usually seamed, as shown at *e* and *d.* When developing the pattern no plan is necessary if both halves of the article are symmetrical.

Draw the side elevation of the transition piece, as shown by A, and on the line 1-5 place the half-profile B. In similar manner on 6-10 place the half-profile C. Divide both B and C into the same number of spaces, as shown from 1 to 5, and 6 to 10. At right-angles to 1-5 and 6-10, from the various points in B and C, draw lines intersecting these lines at 2′, 3′ and 4′, and at 7′, 8′ and 9′. Draw solid and dotted lines in a manner indicated in elevation. These lines in elevation and the various heights in the semi-profiles B and C form the basis with which to construct

the sections in D and E, which show respectively the true lengths of the solid and dotted lines.

For example: To obtain the true length of the solid line 3′ to 8′ in elevation, place this distance as shown by 3′-8′ in D,

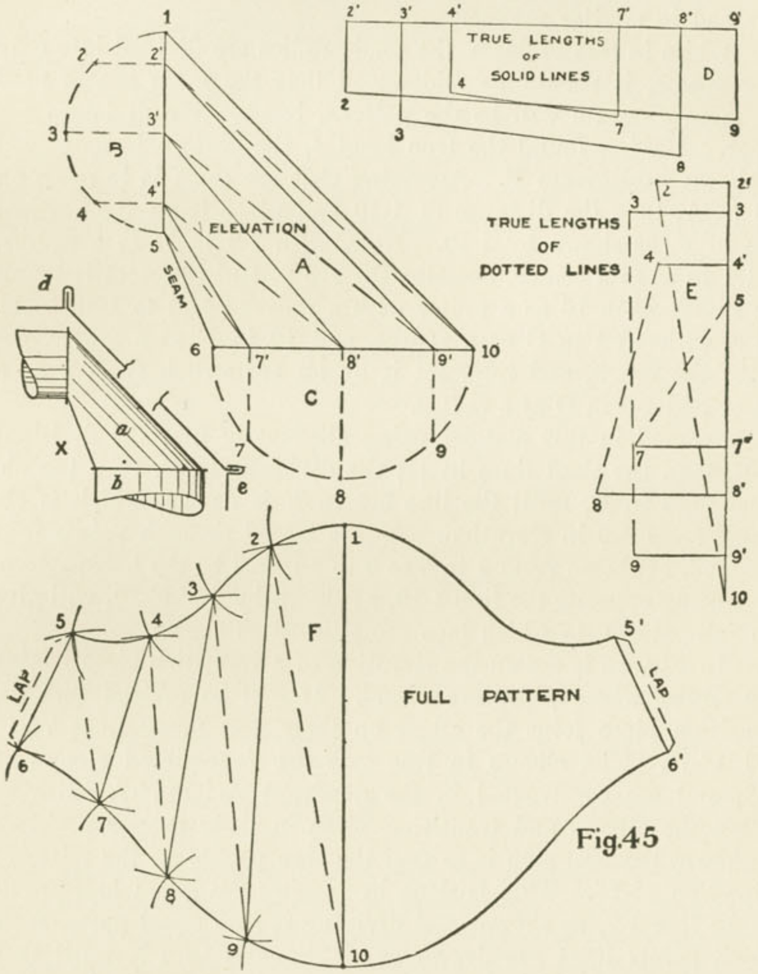


Fig.45

from which erect the perpendiculars 3′-3 and 8′-8 equal to 3′-3 in B and 8′-8 in C. The distance from 3 to 8 in D is then the desired true length. In similar manner are the true distances found for the balance of the solid lines in A, as shown by similar reference numbers in D. Diagram E shows the true lengths of the dotted lines in A.

For example: Take the length of the dotted line 2′-10 and place it as shown by 2′-10 in E. From 2′ erect the prependicular 2′-2 equal to 2′-2 in B. As 10 has no height in the profile C it remains as shown by 10 in E. A line drawn from 2 to 10 in E is the desired true length. The balance of the dotted lines are obtained in similar manner.

While in this problem the semi-profiles are divided into only four spaces, it should be understood that the more spaces used the more accurate will be the pattern, because the divisions are closer. Having found the true lengths, the pattern is developed as shown in diagram F. Assuming that the seam is to come on 5-6 in A, take the distance of 1-10 and place it on the vertical line in F, as shown by 1-10. Now, with 1-2 in B as a radius, and 1 in F as a center, describe the arc 2, and intersect it by an arc struck from 10 as a center with a radius equal to 10-2 in E. Now, with 10-9 in C as a radius, and 10 in F as a center, describe the arc 9, and intersect it by an arc struck from 2 as a center and 2-9 in D as a radius.

Proceed in this manner using alternately first the divisions in B, then the slant lines in E; the divisions in C, then the oblique lines in D, until the line 5-6 in F is drawn, which is obtained from 5-6 in elevation. A line traced through points thus obtained, as shown from 1 to 5 to 6 to 10, will be the half-pattern. By tracing opposite the line 1-10, as shown by 1-5′-6′-10, will give the full-pattern, to which laps are allowed as shown.

In Fig. 46 is shown the elevation of a **transition piece joining two elbows** whose pipes are round. It will be noticed that the transition piece joins the elbow on their first miter lines 7°-1° and 1°-7^v. The elbows in this case are four-pieced elbows of 90°, and are constructed in the quadrant A-1-1^x-7^x-7. Having drawn the elbows and transition piece in their proper positions as shown, the first step is to find the true profile on the miter or joint line 1°-7°. This is done by placing the given half-profile on the line 1-7, as shown, and dividing it into equal parts, from which points lines are drawn at right-angles to 1-7, until they intersect 1°-7°, as shown. From these intersections lines are drawn at right-angles to 1°-7°, making them equal in length to the various distances measured from 1-7 to points 2-3-4-5 and 6, thus obtaining the points 2°-3°-4°-5° and 6°. A line traced through these points will be the true half-profile on the miter line 1°-7°.

As both of the elbows are of similar size and throat (7-A is the throat), then the true profile on 7^v-1° will be the same as that on the line 1°-7°. Having obtained the true profile, and knowing that the true profile on B C is a circle, we are ready to find the sections. The patterns for the elbows are obtained as explained in a previous problem, and can, therefore, be omitted here.

To avoid a confusion of lines, 7^v-1°-7°-B-C has been transferred to Fig. 47, as shown by 7°-1-7-8-8°. On 7°-1 and 1-7 a tracing of the true profile on 1°-7°, in Fig. 46, has been placed as shown by A^1 and A, in Fig. 47. On 8-8° the semi-circle B is placed, representing the half-profile. As the four quarters of

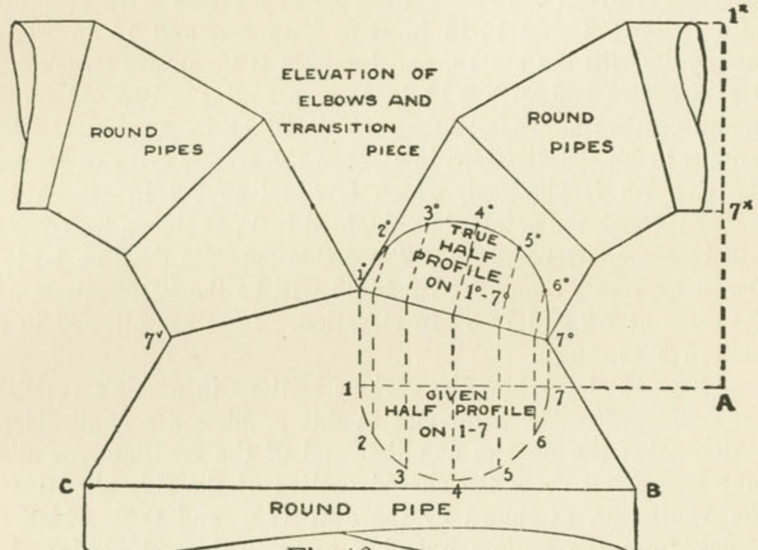


Fig.46

the transition are alike, it will only be necessary to divide the half-profile A into equal parts, as shown from 1 to 7, and divide one-half of the semi-profile B into the same number of spaces as shown from 8 to 14. At right-angles to 8-14′, and from the various points in B, draw lines intersecting 8-14′ at 9′, 10′, 11′, 12′ and 13′. In similar manner, at right-angles to 1-7 from the various intersections in A, draw lines intersecting this line at 2′, 3′, 4′, 5′ and 6′. Draw the usual solid and dotted lines as shown, and proceed to construct the diagrams D and E, which show the true lengths of the solid and dotted lines in C. These solid and dotted lines are obtained in a similar manner, as explained in previous problems.

For example: The true length of the line 3′-12′ in C is obtained by placing this distance on the vertical line in D, as shown from 3′ to 12′. From 3′ and 12′ the perpendiculars 3′-3 and 12′-12 are drawn equal to 3′-3 in the half-profile A and 12′-12 in the half-profile B. A line drawn from 3 to 12 in D is the desired true length.

In similar manner find the true lengths of the solid and dotted lines. The pattern is found by drawing any vertical line in F, as 1-14 equal to 1-14 in D. Now, with 1-2 in the half-profile A as a radius, and 1 in F as a center, describe the arc 2, and intersect it by an arc struck from 14 as a center with 14-2 in E as a radius. Using 14-13 in B as a radius, and 14 in F as a center, describe the arc 13, and intersect it by an arc struck from 2 as a center and with 2-13 in D as a radius. Proceed in this manner, using alternately first the divisions in A, then the true lengths in E; the divisions in B, then the true lengths in D, until the line 7-8 is obtained, which is equal to 7-8 in C. A line traced through the points thus obtained in F, as shown by 1-7-8-14, will be the quarter-pattern. Trace this opposite the line 1-14, as shown by 7°-8°, then 7°-1-7-8-14-8° will be the half-pattern with the seam at 7-8 and 7°-8° in elevation. Laps are allowed in the pattern F as shown.

Fig. 48 shows how the various sections in a **ship's ventilator** are developed. The principles in this problem are applicable no matter what the profiles at either end of the ventilator or elbow may be. First draw the curved outline of the side elevation of the ventilator, as shown by the arcs G L and O T, which are struck from the centers *b* and *a* respectively. Knowing how many sections the elbow is to contain, divide the outlines G L and O T into the desired number; in this case (5), as shown by the points H, I, J, K and P, Q, R and S. Draw lines from G to H to I to J to K to L; also from O to P to Q to R to S to T. Draw the miter or joint lines H S, R I, J Q and P K and add the base tube L O N M. This gives us sections A, B, C, D, E and F.

Draw the profile through M N, as shown by U, in this case a true circle. Draw the profile through G T, as shown by V-W-X-Y, in this case an ellipse. Extend the center line of the ellipse V-X, as shown by V-*s*. In its proper position draw a duplicate

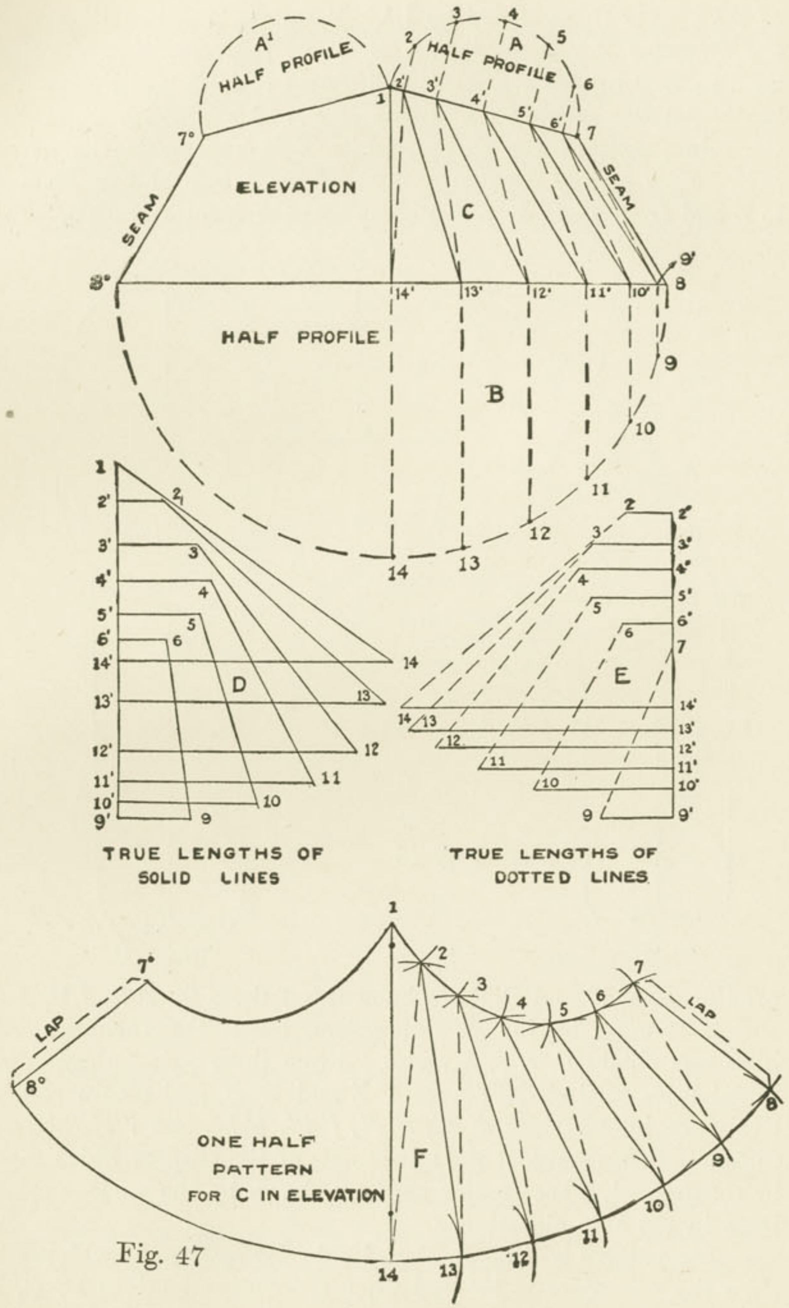


Fig. 47

of the profile U, as shown by U¹. From the profile U¹ establish the diameter Z-& in line with M N in side elevation. Bisect the line G-T in side elevation, and obtain *c*, from which draw the horizontal line cutting the ellipse at *c′* and *c″*, which represents the minor axis of the ellipse, while V-X represents the major axis. Now at any convenient place draw a curved line from *c′* to Z and from *c″* to &, which completes the front elevation. The

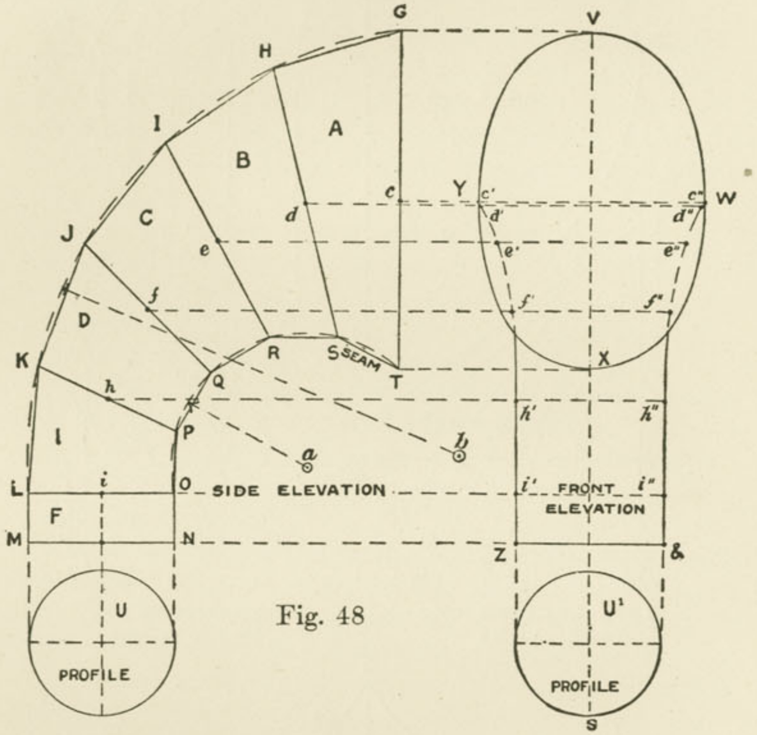


Fig. 48

profiles on M N and G T are known, but those on H S, I R, J Q and K P must be found. Therefore, bisect the various miter lines and obtain *d, e, f, h* and *i*. From these points draw horizontal lines cutting the curves Y Z and W &, and obtain respectively the intersections *d′ d″*, *e′ e″*, *f′ f″*, *h′ h″* and *i′ i″*. These distances then represent the minor axis of the ellipses which must be constructed, whose major axes are shown by the various miter lines in the side elevation.

The pattern will be developed only for section A, which will show the principles to be used when developing sections B, C, D and E. F is simply a straight piece of pipe, whose height is

equal to O N and length equal to the circumference of the profile U.

To avoid a confusion of lines take a tracing of G H S T and place it as shown by 1-7-8-14 in A in Fig. 49. On 1-7 place the semi-ellipse V-W-X, in Fig. 48, as shown by E in Fig. 49. On 8-14 construct the semi-ellipse F, whose semi-minor axis 11′-11 is obtained from one-half of *d′ d″* in front elevation in Fig. 48.

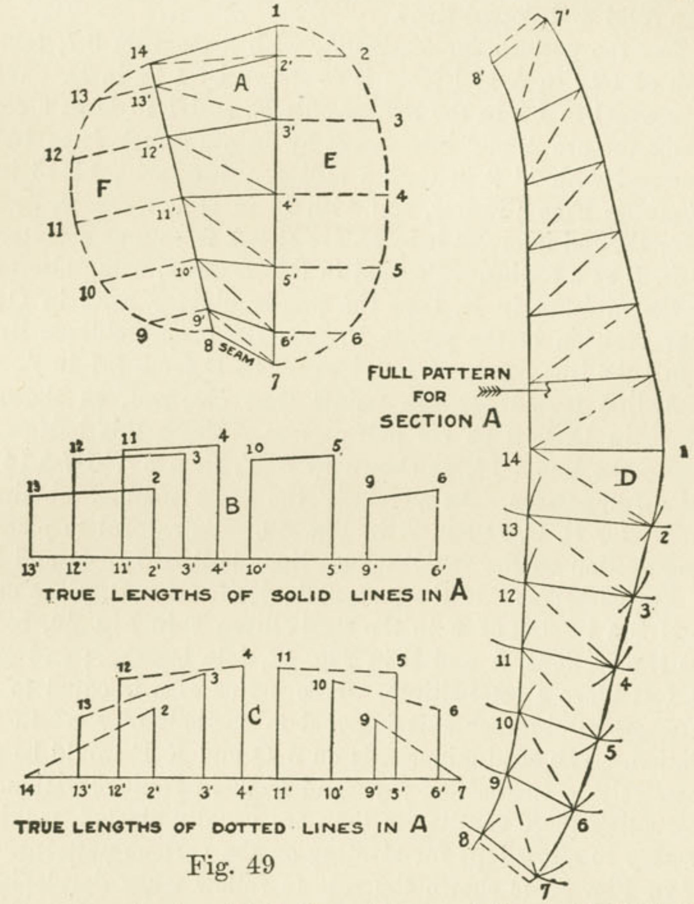


Fig. 49

By any convenient method draw the semi-ellipse 8-11-14 in F in Fig. 49. Divide both the semi-profiles F and E each into equal spaces, as shown from 1 to 7 and 8 to 14. From these points, at right-angles to 1-7 and 8-14, draw lines and obtain the intersections 2′, 3′, 4′, 5′ and 6′, and 9′, 10′, 11′, 12′ and 13′. Connect the solid and dotted lines in the usual manner, as shown in A. These lines then represent the bases of the sections to be constructed, whose altitudes are equal to the heights in the profiles F and E. For example: The length of 10′ 5′ in A is placed on the horizontal line in B, and from 5′ and 10′; the vertical lines 5′ 5 and 10′ 10 are erected equal to 5′ 5 in E and 10′ 10 in F. Draw a line from 5 to 10 in B, which is the true length of the line 5′ 10′ in A. In similar manner obtain the true lengths of the solid and dotted lines.

For the pattern for section A, with a seam on 8 7, take the length of 1 14 in A and place it as shown by 1 14 in D. With a radius equal to 1 2 in the semi-profile E, and 1 in D as a center, describe the arc 2, and intersect it by an arc struck from 14 as a center and with 14 2 in C as a radius. Now, with 14 13 in the semi-profile F as a radius, and with 14 in D as a center, describe the arc 13, and intersect it by an arc struck from 2 as a center and 2-13 in B as a radius. Proceed in this manner, using alternately first the division in E, then the proper oblique lines in C; the proper division in the profile F, then the proper oblique line in B, until the line 8-7 has been obtained in D from 8-7 in A.

A line traced through points thus obtained, as shown by 1-7-8-14 in D, will be the half-pattern. Trace this half-pattern opposite the line 1-14, as shown by 8′-7′, then 8′-7′-1-7-8-14 will be the full-pattern. In precisely the same manner obtain the patterns for B, C, D and E in Fig. 48. Be careful to place the proper section on the various joint lines H-S, R-I, J-Q and P-K.

For example: If the pattern is desired for B, place on the line H S a tracing of F in the semi-ellipse F in Fig. 49, because these two sections, A and B in Fig. 48, join together; and on the line I R place a semi-ellipse, whose major axis is equal to I R, and whose semi-minor axis is equal to one-half of e'-e'' in front elevation. The semi-minor axis on J Q and K P would be equal respectively to one-half of f'-f'' and h'-h'' in front elevation. In constructing these ventilators they are usually riveted, making it necessary to allow laps for riveting on the various patterns.

In Fig. 50 is shown the rule to follow when developing an **open-top coal hod.** First draw the elevation of the body, as shown by 1′-7′-8′-14′, drawing the curve 1′ 7′ at pleasure. Also draw the elevation of the foot F, as shown by 8′-A-B-14′, and extend the sides until they intersect at C. In its proper position below 8′ 14′ draw the plan G, and in its proper position above the top of the hod draw the horizontal section through 1′-7′, as shown by

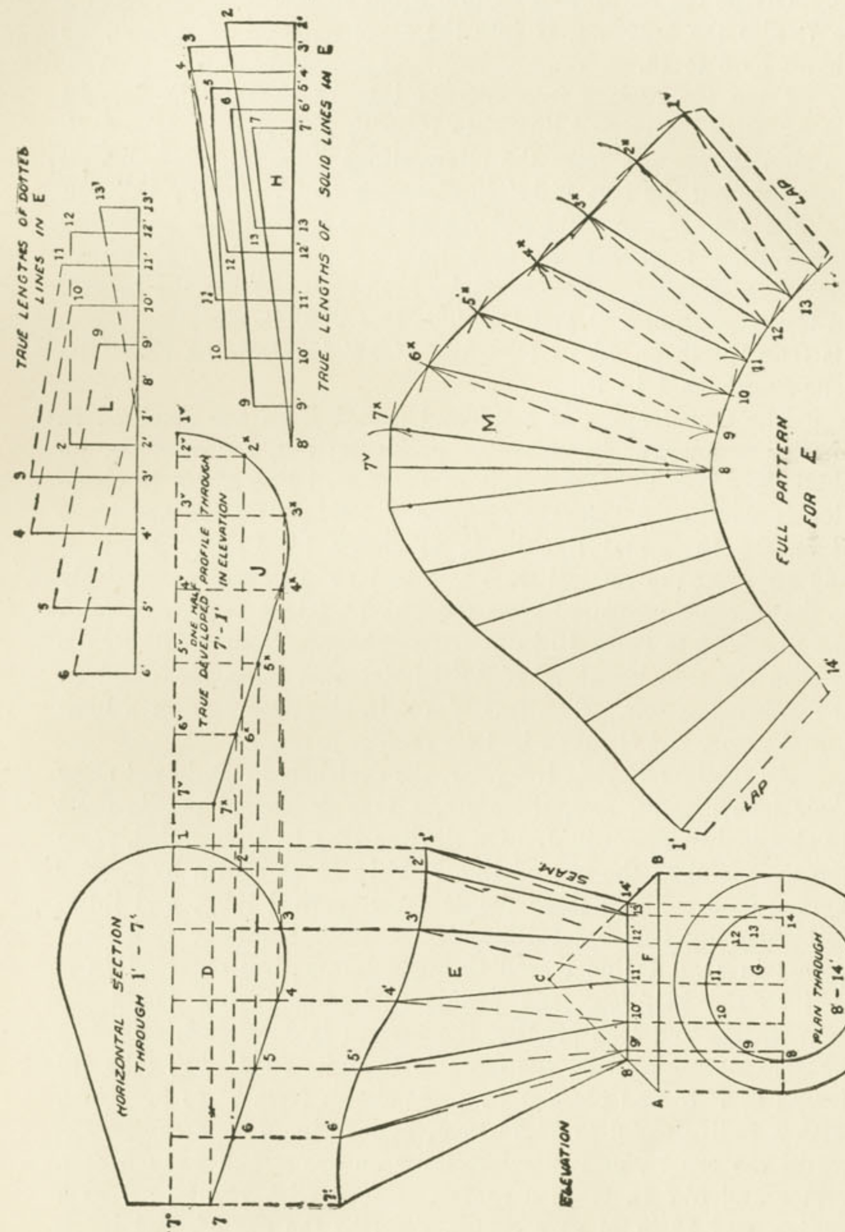


Fig. 50

D. Divide the half-profile D into equal spaces, as shown from 1 to 7, also the half-plan G into the same number of spaces, as shown by 8 to 14.

From the various intersections 1 to 7° in D, drop vertical lines cutting the curved line 1′ to 7′ at 1′, 2′, 3′, 4′, 5′, 6′ and 7′. In similar manner, from the intersections 8 to 14, erect vertical lines meeting the line 8′ 14′ in elevation at 8′, 9′, 10′, 11′, 12′, 13′ and 14′. Draw solid and dotted lines in elevation as shown. These lines represent the base lines of the sections shown in diagrams H and L, whose altitudes are obtained from the heights in the semi-profiles D and G. The line 7′ 8′ in elevation shows its true length on 7° in D, while 1′ 14′ in elevation shows its true length on 1 in D.

The true lengths of solid and dotted lines are obtained in similar manner, as in preceding problems; but, for example, we shall show how the true length of the dotted line 4′ 10′ in elevation is obtained. Take the distance 4′ 10′ in elevation and place it on the horizontal line in L, as shown by 4′-10′. From 4′ and 10′ erect the vertical lines 4′ 4 and 10′ 10 equal respectively to the distance measured from the line 7° 1 to 4 in D, and from the line 8 14 to point 10 in G. The distance from 4 to 10 in L is then the true length of 4′ 10′ in elevation when measured on the finished article. The line 8′ 14′ in elevation lies on a horizontal plane, and G shows its true profile.

As the line 1′ 7′ is irregular, the divisions in D do not show their true lengths, and, therefore, a true developed profile must be obtained as shown in J. On the line 7° 1 in D extended, place the stretchout of the curved line 7′ 1′ in E, as shown by similar figures in J. From these points draw vertical lines, and intersect them by horizontal lines drawn from similarly numbered points in D. A line traced through points thus obtained in J will be the half-developed profile desired. Having found the true lengths and true profiles, the pattern is developed, as shown by M. Assuming that the seam is to come on 1′ 14′, take the length of 7′ 8′ and place it in M, as shown from 7^{v} to 8. Now, with a radius equal to 7^{v} 7^{x} in J, and 7^{v} in M as a center, describe the arc 7^{x}, and intersect it by an arc struck from 8 as a center and 8′-7 in H as a radius. Now, with 7^{x} 6^{x} in J as a radius, and 7^{x} in M as a center, describe the arc 6^{x}, and intersect it by an arc struck from 8 as a center and 8′-6 in L as a

radius. Using 8-9 in G as a radius, and 8 in M as a center, describe the arc 9, and intersect it by an arc struck from 6^{x} as a center and 6-9 in H as a radius.

Proceed in this manner, using alternately first the proper division in the true profile J, then the proper slant line in L; the proper division in the semi-plan G, then the proper oblique line in H, until the line 1^{v}-14 in M is obtained, which is equal to 1′-14′ in E. A line traced through these points, as shown by 7^{v}-1^{v}-14-8 will be the half pattern. As both halves are symmetrical trace opposite the line 7^{v} 8, as shown by 1′ 14′. Then 1′-7^{v}-1^{v}-14-8-14′ is the full-pattern, to which edges are allowed as shown.

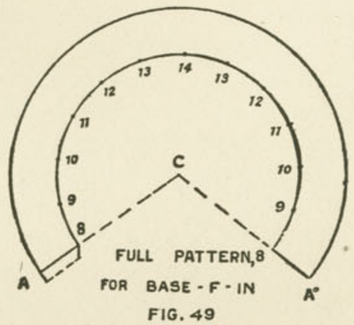
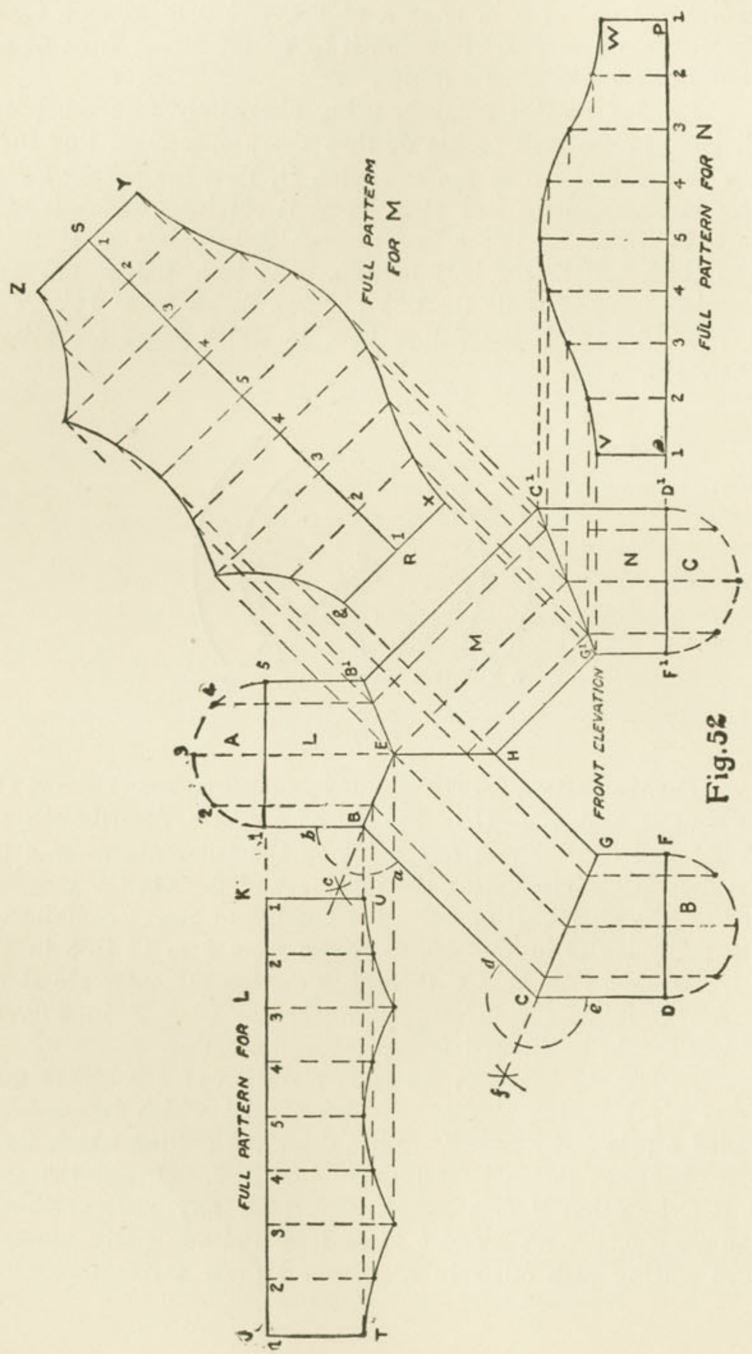


Fig. 51

For the pattern for the foot F in elevation, use C 8′ and C A as a radii, and, with C in Fig. 51 as a center, describe the arcs A A° and 8 8. From any point on the outer arc draw a line from A to C, intersecting the inner arc at 8. On the inner arc lay off the stretchout of twice the number of spaces contained in the semi-plan G in Fig. 50, as shown from 8 to 14 to 8 in Fig. 51. Draw a line from C through 8 cutting the outer arc at A°. A-A°-8-8 is then the full-pattern for the base F in Fig. 50. Edges should be allowed for wiring and seaming.

In Fig. 52 is shown the front elevation of a **Y-branch** made from pipes having similar diameters, and which is sometimes called a *rain-water cut-off*. First draw the outline which the Y is to have, as shown by 1-B-C-D-D^{1}-C^{1}-B^{1}-5. Bisect the angle 1 B C by using B as a center, and, with any radius describe the arc *a b*. With *a* and *b* as centers, and any radius, describe arcs cutting each other in *c*. From *c* draw a line through B,



extending it until it meets the bisection of the opposite angle 5 B^1 C^1 obtained in a similar manner at E. In similar manner bisect the angle B C D by means of *e d f*. From *f* through C draw the line *f* G. On D F place the semi-profile B, and from F erect F G, meeting *f* G at G. From G, parallel to C B, draw G H, and intersect it by a vertical line dropped from E at H. In precisely the same manner draw M and N. As all profiles have the same diameters, place on 1 5 the semi-profile A, on D F the semi-profile B, and on F^1 D^1 the semi-profile C. In practice only half the elevation is necessary.

From the various divisions in A, B and C draw dotted lines, as shown, interesecting the various miter lines C G, B E, E H, E B^1 and G^1 C^1, as shown. For the pattern for the inlet L, place upon the line J K the stretchout of double the spaces contained in A, as shown by similar numbers on J K. From these points draw the vertical measuring lines, and intersect them by horizontal lines drawn from similarly numbered intersections on the miter line B E B^1, and resulting in the miter cut shown from T to U. J-K-U-T is then the full-pattern for L. In similar manner obtain the pattern for N. Place the stretchout of twice C on O P, from which points erect the usual measuring lines, and intersect them by horizontal lines drawn from the various similar intersections on the miter line G^1 C^1. V-O-P-W is then the full-pattern for N, and also answers for the opposite arm C-G-F-D.

For the pattern for the middle section M, draw the line R S at right-angles to B^1 C^1, as shown, upon which place similar stretchout as on J K. At right-angles and through the points on R S draw indefinite lines as shown, and intersect them by lines drawn parallel to R S from similar intersections on the miter lines G^1 C^1 and B^1 E H. A line traced through points thus obtained, as shown by & Z and X Y, will be the desired miter cuts. X-Y-Z-& is then the full-pattern for M. To all patterns laps must be allowed for seaming or riveting.

Classification of Locomotives

[WHYTE'S SYSTEM]

040	4 WHEEL	064	FORNEY 6 COUPLED
060	6 WHEEL	046	" 4 "
0440	ARTICULATED	066	" 6 "
0660	ARTICULATED	242	COLUMBIA
2440	ARTICULATED	262	PRAIRIE
080	8 WHEEL	282	"8 COUPLED"
240	4 COUPLED	2102	10 "
260	MOGUL	244	4 "
280	CONSOLIDATION	264	6 "
2100	DECAPOD	284	8 "
440	8 WHEEL	246	4 "
460	10 "	266	6 "
480	12 "	442	ATLANTIC
042	4 COUPLED & TRAILING	462	PACIFIC
062	6 " " "	444	4 COUPLED DOUBLE ENDER
082	8 " " "	464	6 " "
044	FORNEY 4 COUPLED	446	4 " "

The locomotive classification adopted by the American Locomotive Company is based on the representation by numerals of the number and arrangement of the wheels commencing at the front. Thus, a Mogul locomotive with a two-wheel leading truck, six driving wheels and no trailing truck, would be classified as a 260 type.

The total weight is expressed in 1,000 of pounds. For example, an Atlantic locomotive weighing 176,000 pounds would be classified as a 442-176 type. If the engine is compound, the letter C should be substituted for the dash; thus, 442 C 176 type. If tanks are used in place of a separate tender, the letter T should be used in place of the dash. Thus a double-end suburban locomotive with two-wheeled leading truck, six drivers and six-wheeled rear truck, weighing 214,000 pounds, would be a 266 T 214 type.

Types of Locomotives

American Locomotive Co.'s Classification. The method of describing locomotives which has become general in this country is based upon the wheel arrangement of the engine. Beginning at the front of the engine, the number of wheels in the engine truck, the drivers and the rear truck are given, each figure being separated by a dash or hyphen. Thus the well-known Atlantic type, according to this rule, is spoken of as a 4-4-2 engine, a Mogul type as a 2-6-0, a six-wheel switching engine as a 0-6-0, the cipher denoting that no trailing truck is used. There are always three figures in the designation, and each represents the total number of the set. The number of wheels in the engine trucks are given first, then the number of drivers, and lastly the rear truck. The classification adopted by the American Locomotive Co. is shown in the accompanying table.

In addition to describing the locomotive by its wheel arrangement, the weight and type of locomotive may also be included in the numerical designation. The total weight is expressed in 1,000 pounds. Thus, an Atlantic locomotive weighing 176,000 pounds would be classified as a 442-176 type. If the engine is compound, the letter C should be substituted for the dash; thus, 442-C-176 type. If tanks are used in place of a separate tender, the letter T may be used in place of the dash. Thus a double-end suburban locomotive with a two-wheel leading truck, six drivers and six-wheeled rear truck, weighing 214,000 pounds, would be designated as a 266-T-214 type.

Baldwin's Designation. The Baldwin Locomotive Works use a somewhat different designation for their locomotives, which, while not generally understood, is of considerable importance on account of the large number of locomotives which this fi m builds. Each Baldwin locomotive has the builder's number plate attached to the sides of the smoke-box directly over the steam chest, except in small engines, when it is placed on the smoke-box door, or in some other conspicuous position. This plate contains the name of the manufacturers, the consecutive construction number of the engine, and the year in which it was constructed.

The different classes of locomotives are designated by a combination of figures and one of the letters A, B, C, D, E or F.

The letter A indicates that there are no traction driving wheels, and that the locomotive is driven by gear wheels engaging in a rack-rail or rails; the letter B indicates that two wheels are connected as driving wheels; the letter C indicates that four wheels are coupled; the letter D indicates that six wheels are connected as driving wheels; the letter E indicates that eight wheels are connected as driving wheels; the letter F indicates that ten wheels are connected as driving wheels.

A figure (4, 6, 8, 10, 12, or 14) is used to denote the whole number of wheels under the locomotive.

A figure, or figures, following the figures indicating the whole number of wheels, indicates the diameter of cylinders, viz.:

8	indicates	cylinders	7	inches	in	diameter
10	"	"	8	"	"	"
12	"	"	9	"	"	"
14	"	"	10	"	"	"
16	"	"	11	"	"	"
18	"	"	12	"	"	"
20	"	"	13	"	"	"
22	"	"	14	"	"	"
24	"	"	15	"	"	"
26	"	"	16	"	"	"
28	"	"	17	"	"	"
30	"	"	18	"	"	"
32	"	"	19	"	"	"
34	"	"	20	"	"	"
36	"	"	21	"	"	"
38	"	"	22	"	"	"
40	"	"	23	"	"	"
42	"	"	24	"	"	"

Thus 8-26 C indicates an eight-wheeled locomotive, having four wheels coupled, and cylinders sixteen inches in diameter; 8-26 D indicates an eight-wheeled locomotive, having six wheels coupled, and cylinders sixteen inches in diameter; ard 10-34 E, a ten-wheeled locomotive having eight wheels coupled, and cylinders twenty inches in diameter.

The same rule applies to Baldwin four-cylinder compound locomotives (Vauclain System). Thus 10-$\frac{22}{24}$ D indicates a ten-wheeled locomotive, having six wheels coupled, a fourteen inch high-pressure cylinder on each side, and a twenty-four inch low-pressure cylinder on each side.

The addition of the fraction $\frac{1}{4}$ indicates that there is a truck at each end of the locomotive. Thus 8-26$\frac{1}{4}$ C indicates an eight-wheeled locomotive, having four wheels coupled, cylinders sixteen inches in diameter, and a two-wheeled truck at each end.

The addition of the fraction $\frac{1}{3}$ indicates that the engine is on the " Forney " plan, having the truck back of the fire-box. Thus 8-26 $\frac{1}{3}$ C indicates an eight-wheeled locomotive, having four-wheeled truck back of the fire-box. 6-26 $\frac{1}{3}$ C indicates a six-wheeled locomotive, having four wheels coupled, cylinders sixteen inches in diameter, and a two-wheeled truck back of the fire-box.

The figures following the class designation, as found on every Baldwin locomotive, give the class number for that locomotive, and supply an individual designation for it, in addition to the construction number. Thus 8-26 C 500 means the five-hundredth locomotive of the 8-26 C class.

FREIGHT LOCOMOTIVES.

Among the various types of locomotives used for freight service are the Consolidation, or 2-8-0 type; the Mallet; the Santa Fe, or 2-10-2 type; the Decapod, or 2-10-0 type; the Mikado, or 2-8-2 type; the ten-wheel, or 4-6-0 type; the twelve-wheel, or 4-8-0 type; the Mogul, or 2-6-0 type; the Prairie, or 2-6-2 type; and the 0-10-0, 0-8-0 and 0-6-0 types.

By far the largest number of locomotives in use for freight service belong to the Consolidation or 2-8-0 type. These are

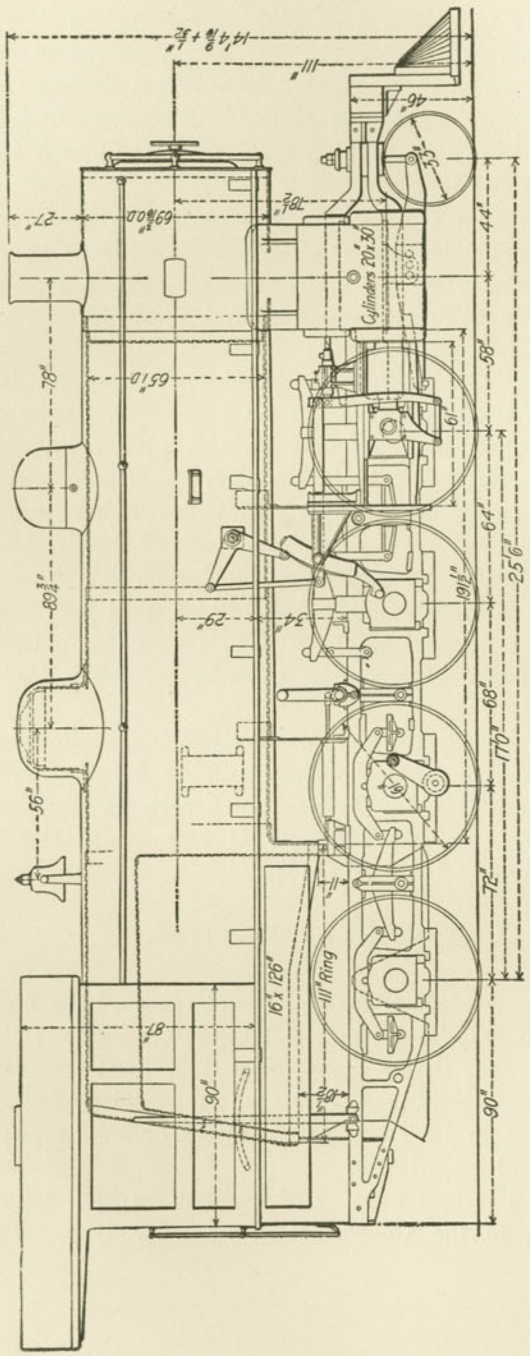


Fig. 1.

Side Elevation of Consolidation Type Freight Locomotive Used on the Boston & Maine R. R.

either of the simple or compound type, and are equipped with either the Walschaert or Stephenson link motion. The average steam pressure carried is about 200 pounds per square inch. The type of boiler used is either of the Wooten, radial stay, wagon top, extended wagon top, straight, or Bellpaire design.

Consolidation, or 2-8-0 Type. For freight service requiring high starting power, a large proportion of weight on driving wheels is necessary. For road service, as distinguished from yard or switching work, guiding wheels in front of the leading driving-wheels are desirable. Not only must the power in starting be high, but hauling capacity must be sustained for long periods. These factors are available in a wide range of weights and capacities in the 2-8-0 type, which combines them to such an extent as to give this type the leading position in freight service under present conditions. In general terms it may be called the favorite type for freight service handled at low and moderate speeds. For service requiring more than six coupled driving wheels, and yet which lies within the tractive power possibilities of eight driving wheels, it is an ideal type. With relatively small driving wheels and large cylinders, its tractive effort is adapted to starting heavy trains and working steep grades. It is also a most satisfactory type for freight service on light rails or poor roadbed. The weight, being distributed over eight driving wheels, keeps the load per wheel within the limits of capacity of the rail, while the total adhesive weight is much greater than could be carried on the same rail in a 4-6-0 or 2-6-0 type. Though not generally recommended for what may be termed fast freight trains, under certain road and traffic conditions, this type with the proper ratio of heating surface to cylinder volume may be used to good advantage in that class of service, and many Consolidation locomotives are successfully hauling such trains.

The 2-8-0 wheel arrangement, as shown in Figs. 1 and 2, places a large proportion of the total weight upon the driving wheels, and provides a leading two-wheel truck for guiding purposes. As large a proportion as 90 per cent of the total weight has been placed upon the driving wheels of the 2-8-0 type. A large number of locomotives of this type show an average of 88½ per cent upon driving wheels.

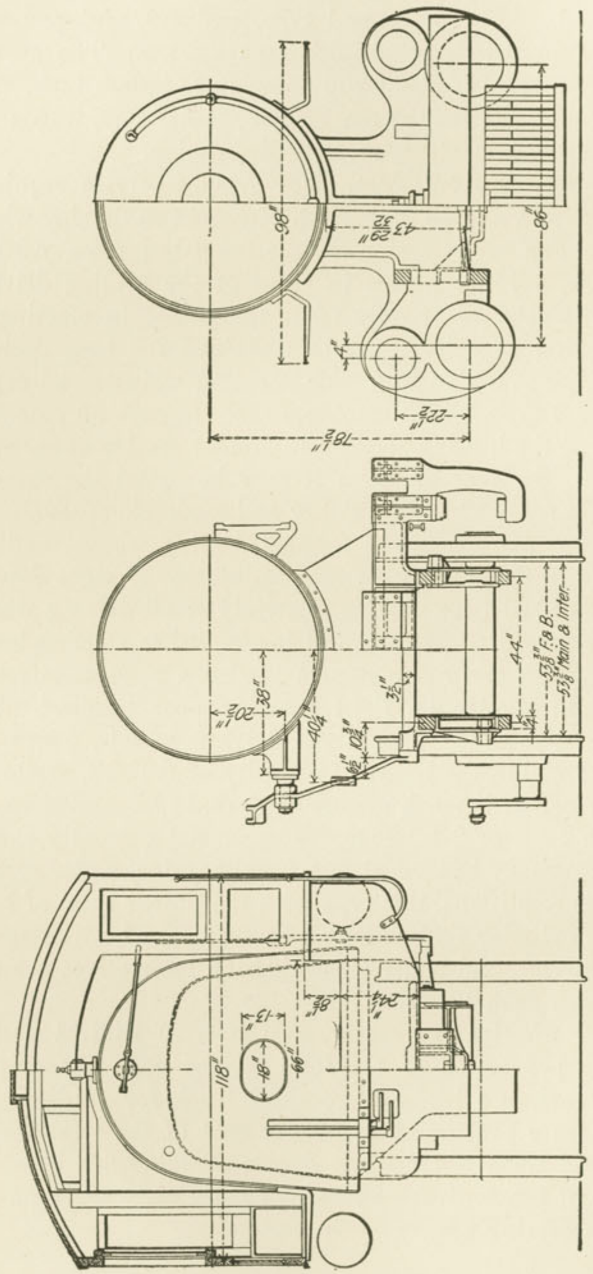


Fig. 2.

Sections and End Elevations of Consolidation Type Freight Locomotive Used on the Boston & Maine R. R.

Boilers of sufficient capacity for moderate speeds may be provided in this type, and the fire-box may be placed over the driving wheels, if it is necessary, to obtain sufficient width of grates and ample area for any kind of fuel. This type lends itself to wide variations in grates and fire-boxes. The relatively small driving wheels render it nearly as easy to design a wide fire-box with wide water spaces as in the case of the 2-6-2, 4-6-2 and 2-8-2 types with trailing wheels. To secure a desirable depth at the front end of the fire-box the mud ring may be sloped downward towards the front, terminating between the third and fourth pairs of driving wheels and below the tops of these wheels.

Locomotives of this type have been built with a large variety of total weights and hauling capacities, the weights ranging from 60,000 to 250,000 pounds, with hauling capacities adapted to wide variations in road and service conditions.

Mallet Articulated Compound Locomotive, or 0-8-8-0 Type. Of the types of Mallet engines in use for freight service all are of the compound type, equipped with Walschaert valve gears. The type of boiler used is either of the Bellpaire, straight or conical type. The name of this type of engine is derived from a French engineer, Anatole Mallet, who first succeeded in having two small engines of this type tried on a French railway. These engines immediately became very popular in Europe on lines with sharp curves.

The articulated or jointed feature is that with which Mallet's name is associated. This feature permits of the use of a maximum effective wheel base with a very much reduced rigid wheel base. The driving wheels are arranged in two sets or trucks, the front one being constructed so that while its cylinders take steam from the boiler, and while it carries weight, it is able to swing under the boiler so as to accommodate itself to curves.

The term Mallet Compound applies only to the arrangement of the cylinders and driving wheels with separate sets of frames connected through a hinged joint, and does not include any particular design of compounding as concerns the distribution of steam. The Erie locomotives, and also the ones on the Baltimore & Ohio, are compounded on the Mellin system, which employs an automatic intercepting and reducing valve for admitting live steam at a reduced pressure to the low pressure cylinders in starting, and for increasing the pressure in those cylinders at any other desired time. The locomotives on the Great Northern Railway are designed with a plain system of cross-compounding without intercepting valves or other automatic arrangements, having, however, a small pipe connection from the boiler to the receiver pipe, by means of which live steam can be admitted at the discretion of the engineer.

The Mallet Articulated Compound Locomotive has been known and used in certain mountainous sections of Europe for several years past; but it has only been recently that it has been modified and adapted to American requirements. The essential features are a locomotive with all of its weight on drivers, having tractive power greatly in excess of any previous American locomotive, and at the same time possessing a certain flexibility of construction which makes it possible to operate it on roads having maximum grades and curves. It is practically two separate locomotives combined in one, and advantage is taken of the opportunity to introduce the compound principle under most advantageous and favorable conditions.

This type of locomotive is designed and built to provide the maximum amount of power which is likely to be required in operating over mountain grades, even under extreme conditions.

In a test on the New York Central, on the heavy grade near Schenectady, N. Y., a train of 83 loaded cars was moved with a heavy Consolidation locomotive in front and the Mallet Articulated Compound in the rear. The latter locomotive pushed 62 of the 83 cars, showing that it did 75 per cent of the work, which, under ordinary conditions, would have required the use of three heavy switching locomotives as pushers.

Comparison of the Mallet Compound Engine with the Consolidation Type. Compared with the heaviest Baltimore & Ohio Consolidation locomotive, the Mallet Articulated Compound shows 90.2 per cent increased weight on drivers, while the total weight of locomotive is increased only 72.8 per cent; and the heating surface is increased 97.6 per cent.

While the articulated locomotive is looked upon at present as a hill climber and a "helper," it will be found that it is also a

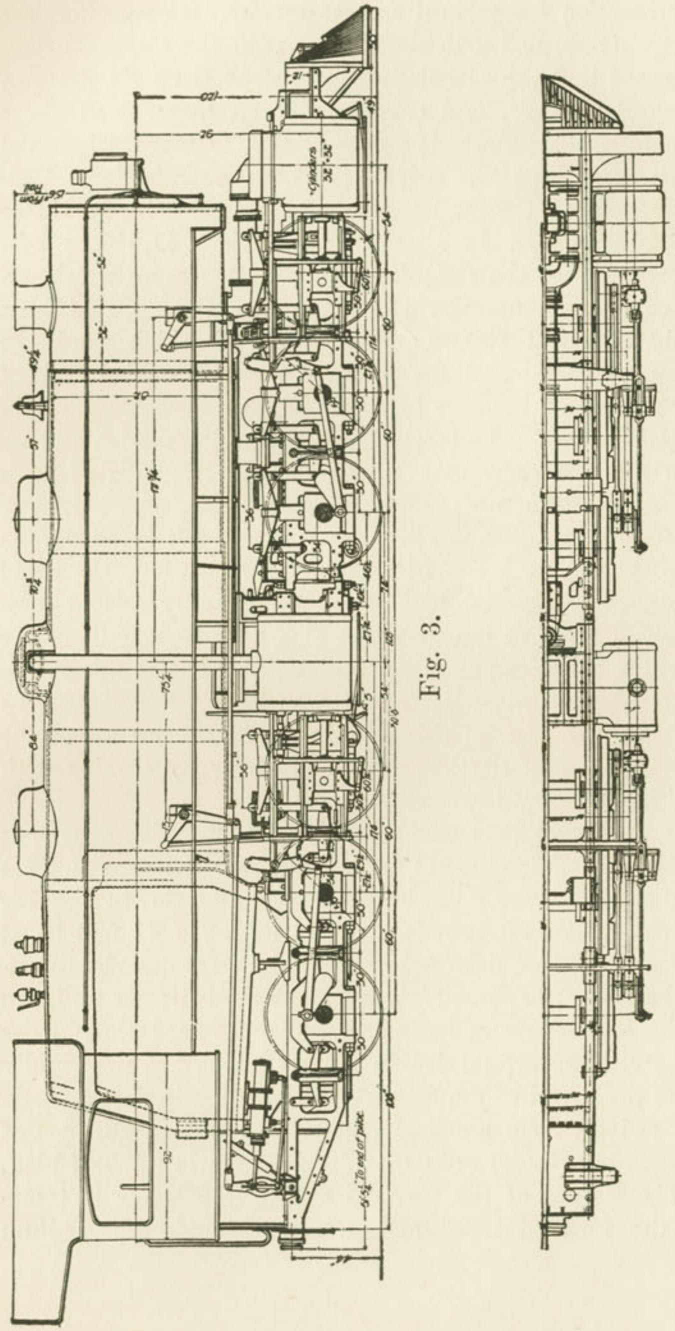


Fig. 3. Fig. 4.

PLAN AND ELEVATION OF THE MALLET ARTICULATED COMPOUND ENGINE USED ON THE B. & O. RAILROAD.
(*American Locomotive Company.*)

valuable locomotive for general freight service. Comparing, for example, the six-coupled articulated type with the Consolidation, it will be noted that the distribution of weight is on six pairs of drivers instead of four, and consequently an increase of about 50 per cent in hauling power is secured. For instance, where the weight limit on each pair of drivers is 45,000 pounds, for a Consolidation locomotive the total weight of the locomotive would be about 200,000 pounds, and the tractive power about 41,000 pounds. With a locomotive of the articulated type of the same weight on each pair of drivers, namely, 45,000 pounds, there would be a total weight of about 270,000 pounds, all of which would be utilized for adhesion, and the tractive power would be about 61,500 pounds, or an increase in power of 50 per cent, with only 35 per cent increase in the total weight of the locomotive and no increase in the rail pressure per pair of drivers. The division of the wheel base into two groups, well separated, makes it very favorable for bridges. It is also easy on the track in curves, as each group of wheels being independently connected, the rigid wheel base need not exceed 10 feet for an ordinary freight locomotive. These types of locomotives which have been built so far in this country are of great power and weight, but the design is equally well adapted to moderate and even light locomotives. In fact, the greatest number of this type in use in Europe are of the latter description, and the same ratio of efficiency obtains with them as with the heavy locomotives.

Mallet Compound Used on the B. & O. R. R. The enormous size of this type of locomotive built for the Baltimore & Ohio Railroad is realized from Figs. 3 and 4. The weight, in working order, is nearly 335,000 pounds, and the flues are 21 feet long; the rear three parts of drivers are carried in frames rigidly attached to the boiler; to these frames, and to the boiler as well, are attached the high pressure cylinders. The forward three pairs of drivers are, however, carried in frames which are not rigidly connected to the barrel of the boiler, but which are in fact a truck. This truck swivels from a centre pin, located just in advance of the high pressure cylinder saddle, as may be seen in the half plan, Fig. 4. The weight of the forward end of the boiler is transmitted to the forward truck and drivers through the medium

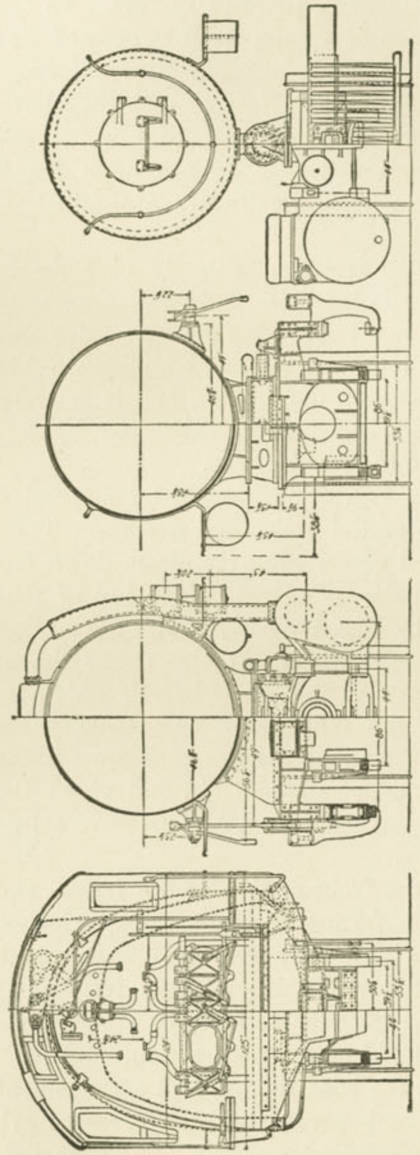


Fig. 5. Fig. 6. Fig. 7. Fig. 8.

Sections Through Mallet Compound Used on the B. & O. R. R.

of sliding bearings, which may be seen in elevation. Fig. 3, between the second and third pairs of drivers. In order to secure the proper distribution of weight, the back ends of the front frames are connected by vertical bolts with the front ends of the rear frames. These bolts are so arranged that they have a universal motion top and bottom, which permits of a certain amount of play between front frames and rear frames when the locomotive is curving. The low pressure cylinders are attached to the forward or truck frames.

The steam dome is placed directly over the high pressure cylinders, and steam is led from the dome down to the outside of the boiler on either side to the high pressure valve chambers. The steam, after having been used in the high pressure cylinders, passes to a jointed pipe between the frames, and is delivered to the low pressure cylinders, whence it is exhausted by a jointed pipe through the stack in the regular way.

The back end, Fig. 5, represents no unusual feature other than the great size of the boiler and fire-box. The section, Fig. 6, shows the method of bringing the steam down from the steam dome to the high pressure valves, which are of the piston type. The section given by Fig. 7 clearly shows the sliding support between boiler and front truck. It also shows the method of attaching the lift shafts to the boiler barrel, which is made necessary by the use of the Walschaert, or outside, valve gear. The section in Fig. 8 shows that the low pressure cylinders are fitted with slide valves, and also shows (in end view) the jointed exhaust pipe which leads back from low pressure cylinder saddle to bottom of smoke-box.

Fig. 9 shows the front section of the frame, and Fig. 10 its rear section. These frames are exceptionally heavy and strong, and the splices are unusually long and well bolted and keyed. The connecting bolt between the forward frame and rear frame is shown in part at the rear end of the forward section and in part at the forward end of the rear section.

Fig. 11 shows the construction and arrangement of the flexible pipe connections between the high pressure cylinder saddle and the low pressure cylinder saddle (this pipe connection serving as a receiver); also the exhaust connection between the low

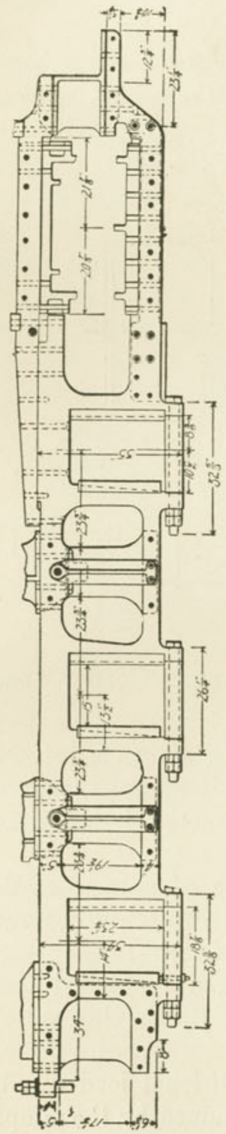


Fig. 9.

Main Frame, Front Section, B. & O. Mallet Compound.

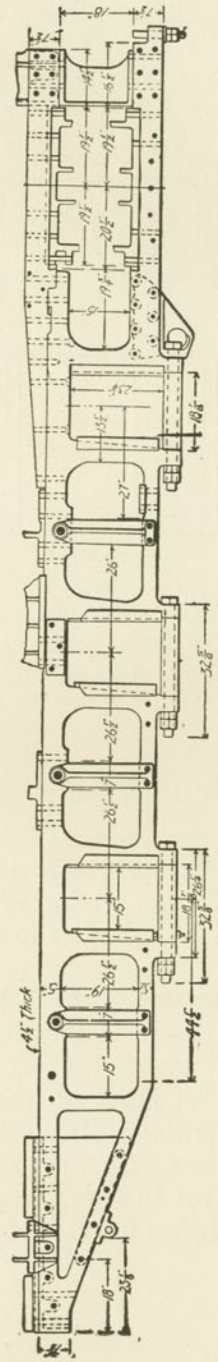


Fig. 10.

Main Frame, Back Section, B. & O. Mallet Compound.

pressure cylinder saddle and the base of the smoke-box. It will be noticed that the longer pipe is made up of three sections; this division into parts having been arranged so that the several parts can be put into place or removed from place without undue difficulty. The ball joints are ground in, and, as an extra precaution, vulcabeston gaskets are provided; the construction being such that the gland may be tightened on to the gasket without gripping the ball joint. Similarly, slip joints are provided to cover variations in the length, due to carving, etc.

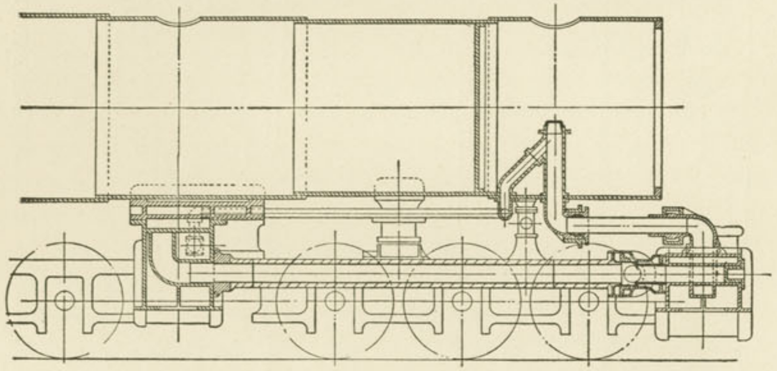


Fig. 11.

Flexible Pipe Connections Used on Mallet Compounds.

Fig. 11 also shows, in section, the sliding supports between boiler and front truck, and, incidentally, the direct exhaust from high pressure cylinders to stack when the locomotive is being run simple.

Advantages of the Mallet Compound. The advantages of the Mallet Articulated form of construction and compounding over the simple locomotive may be summarized as follows:

1. That about 50 per cent more load can be hauled than with the ordinary simple locomotive having eight driving wheels and the same weight per axle.

2. That in heavy work 50 per cent additional load can be hauled with no increase of fuel over that consumed by the simple

locomotive. This is equivalent to a saving in fuel of $33\frac{1}{3}$ per cent on the ton mile basis.

3. That this additional load is hauled by the same effort of the crew.

4. That a higher tractive power is obtained to the weight per axle than with the ordinary locomotive, as the chief cause for slipping, namely, the accumulation of high unbalanced pressure at the points of wheel and rail contact does not occur at the same time in both engines. When one engine starts slipping there follows a reduction in unbalanced pressure, and it regains thereby its grip on the rail without making it necessary to shut off, or even throttle, the steam supply. The other engine, meantime, has been gaining power, and thus preventing any loss of speed and consequent stalling of the train at a critical moment. These conditions are the same whether the slipping occurs with the high pressure or the low pressure engine, and have been amply proved in practice. The most frequent cause for stalling with the simple locomotive is thus overcome.

5. That all the weight of the locomotive is utilized for tractive purpose.

6. That the shorter rigid wheel-base offers less resistance in curves, and is in consequence easier on the track.

7. That a reserve power of about 20 per cent above the normal power of the locomotive is obtainable by turning live steam into all the cylinders and running the locomotive simple, which can be done at the will of the engineer when the conditions require it.

8. That the running gear and the various parts of the machinery in general are much lighter and more accessible for attention and repair.

The first locomotive of the Mallet type to be built in this country was constructed in 1904 for the Baltimore & Ohio Railroad. At that time the design was looked upon with considerable suspicion by many railroad men. However, after being exhibited at the St. Louis Exposition, the locomotive was put into pushing service on the mountains, and within a comparatively short time proved to be a complete success in every respect.

Mallet Compound Engines Used on the Erie R. R. All records of weight, size and power of locomotives were broken by the completion, at the Schenectady Works of the American Locomotive Company, of three Mallet Locomotives for the Erie Railroad. These locomotives each weigh 409,000 pounds, all of which comes on the eight pairs of drivers. They have a boiler measuring 84 inches outside diameter at the front end, containing 21 ft. tubes and a 4 ft. combustion chamber, and a fire-box with 100 sq. ft. of grate surface, in which soft coal is burned. The tractive effort operating as a compound is 94,800 pounds. The locomotive and tender measure nearly 85 ft. in length over all. It is nearly 15½ ft. in height, and has a width of 11 ft. at the low pressure cylinders. This locomotive, while exceeding the Baltimore & Ohio engine by 65,000 pounds in weight and nearly 24,000 pounds in tractive effort, is of practically the same design in all its essential details.

While the Erie Mallet engines shown in Fig. 12 are of a weight and size which a short time ago would have been considered practically impossible for a locomotive, they cannot really be looked upon as experimental, as they are now in successful operation. They are used in pushing service between Susquehanna and Gulf Summit, where the ruling grade is 1.3 per cent. Having a tractive effort of nearly 95,000 pounds, they are capable of handling about 2,600 tons, exclusive of the locomotive, on this grade.

In spite of the fact that this locomotive weighs 409,000 pounds, it has a weight per driving axle which is less than many large freight locomotives now in service, and less than any previous Mallet Compound locomotive, except ones for road service on the Great Northern Railway. One of the features of greatest advantage of the Mallet type is that an enormous amount of power can be centered in one machine, which will be capable of operating over the same track that other heavy freight locomotives use.

The boiler is of the radial stay type, with conical connection sheet, the inside diameter of the first ring being 82 inches and that of the largest course being 96 inches. The heaviest ring of the shell is 1 3-16 inches thick. A steam pressure of 215 pounds is carried. The tubes, of which there are 404, are 21 ft. long, and are 2¼ inches in diameter. This length of tube, taken in connection with the 4 ft. combustion chamber, places the front tube sheet 25 ft. from the fire-box, a figure which has never before been

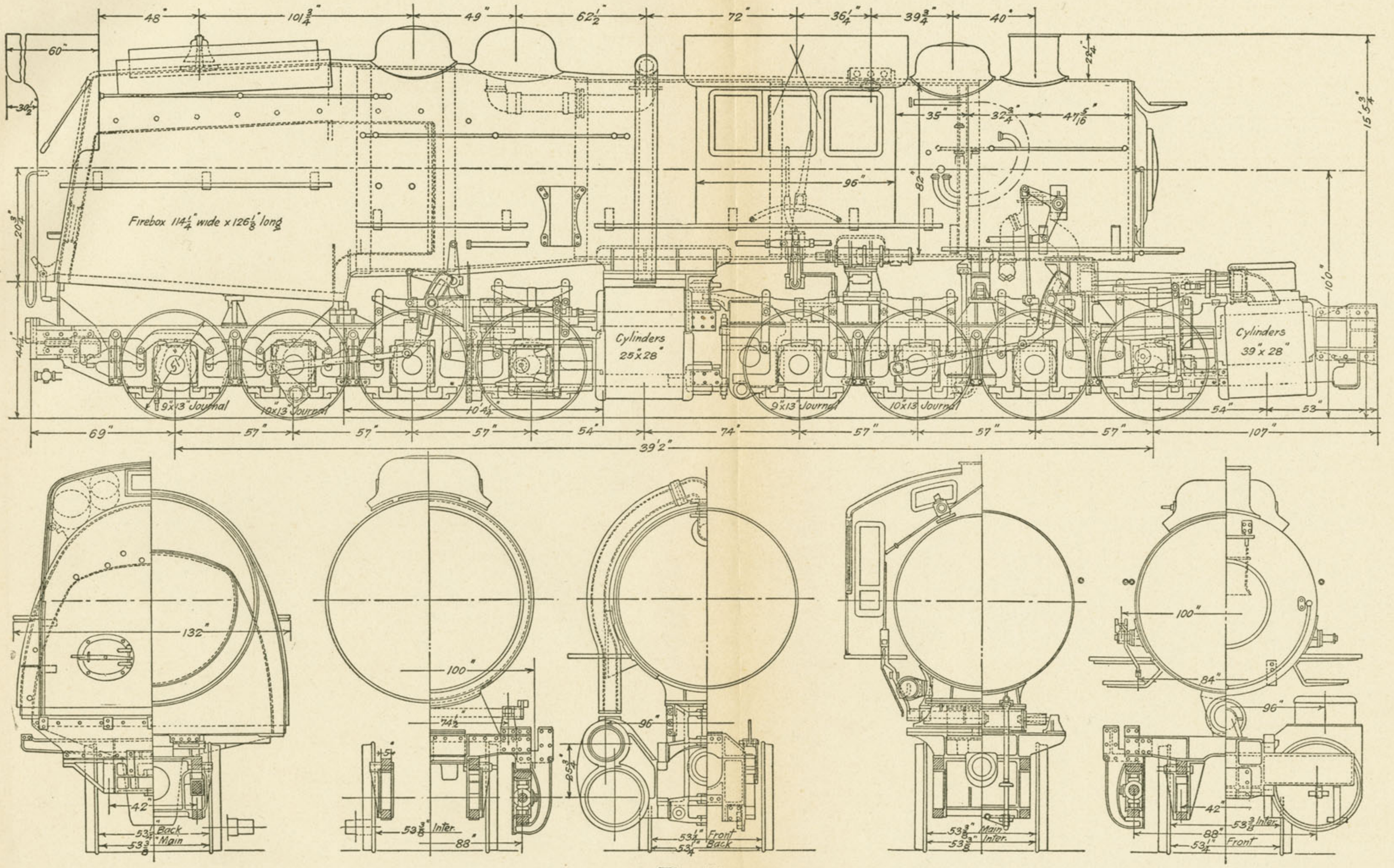


Fig. 12.

MALLET TYPE OF COMPOUND LOCOMOTIVE USED ON THE ERIE R. R.

equalled in locomotive service. The combustion chamber itself is radially stayed from the shell of the boiler, and is provided with ample water space on all sides. The mud ring is 5 inches in width at all points, and the crown sheet has a slope of 5 inches from its connection with the combustion chamber to the door sheet. The dome is placed about central in the length of the boiler, since the locomotive is to operate in either direction and on heavy grades.

The boiler of the Erie engine is fitted with a 4 ft. combustion chamber, which considerably reduces the amount of total heating surface in comparison with its size and grate area. The indications, from the service already given by combustion chamber locomotives, are that the efficiency and the power of the boiler are not reduced by this installation, and hence the ratios of but 53 sq. ft. of heating surface per sq. ft. of grate area, and of but 222 sq. ft. per cubic ft. of cylinder volume, do not really indicate that the boiler is not of sufficient size as compared with those of the other designs.

Owing to the extreme width of the fire-box, the cab is placed over the boiler shell near the front, and hence all the controlling apparatus, injectors, etc., are located on the righthand side. The injectors feed through a double check valve located on the center line of the boiler, but a short distance back of the front tube sheet.

The high pressure cylinders, which have a diameter of 25 inches and a stroke of 28 inches, are very similar to those used on the Baltimore & Ohio locomotive. They are cast in pairs with saddles, the separation between the two cylinders, however, being 8½ inches to the right of the center. This permits the intercepting valve to be placed in the lefthand cylinder casting, and also gives room for the connection to the receiver pipe. The exhaust steam from the right cylinder continues from the passage in its saddle to an outside U-shaped pipe connecting to a passage in the left-hand cylinder casting, which leads up to the intercepting valve chamber, into which the exhaust steam from the left cylinder also passes. From this point the exhaust steam passes to a 9-in. receiver pipe extending forward between the frames to the low pressure cylinders. An extra exhaust connection is provided in the side of the left cylinder casting, which has a 4½ inch pipe leading to the exhaust pipe in the smoke-box. This connection is made by a pipe having universal joints in a manner similar to the receiver pipe. The construction of the receiver pipe is such as to permit free movement of the joint frames in all directions, it being fitted with a ball joint at either end and a slip joint near the forward end. It is arranged to permit the locomotive to pass around 16-degree curves. The low pressure cylinders are cast in pairs, the connection to the receiver pipe being made through a Y-shaped casting connecting at the back to the cored passages in the cylinder. The exhaust is carried through an elbow located on top, and in the center to a short-pipe with universal joints leading to the exhaust pipe in the front end.

The high pressure cylinders are fitted with piston valves having internal admission, while the low pressure cylinders, which are 39 inches diameter and 28 inches stroke, have balanced slide valves, with external admission. The valve gear, which is of the Walschaert type, is so arranged that the return crank leads the pin in both sets, and hence the block is at the bottom of the link for the go-ahead motion for the low pressure cylinders, and at the top of the link for the high pressure cylinders. In this way the weights of the two valve gears counterbalance each other. The operation of reversing is further assisted by a pneumatic reversing device, which is connected to the reverse lever and consists of two cylinders, one of which contains oil under pressure for locking the device in any desired position, the other cylinder being the air cylinder. The operation of this device is controlled from an auxiliary reversing lever in the cab.

In the construction of the cast-steel frames, the articulated connection between the two groups is made by means of a hinge joint, which is formed in the castings secured ahead of the high pressure cylinder. The vertical bolts connecting the upper rail of the front group with the lower rail of the rear group are fitted with ball joints to permit free movement of the two frames relative to each other, and are provided for holding the frames in line and preventing binding on the hinged connection.

The weight of the boiler, extending beyond the high pressure cylinder saddle, is transferred to the front set of frames at two points, which are normally in contact, and two other points, which will come into contact under unusual conditions. The one which

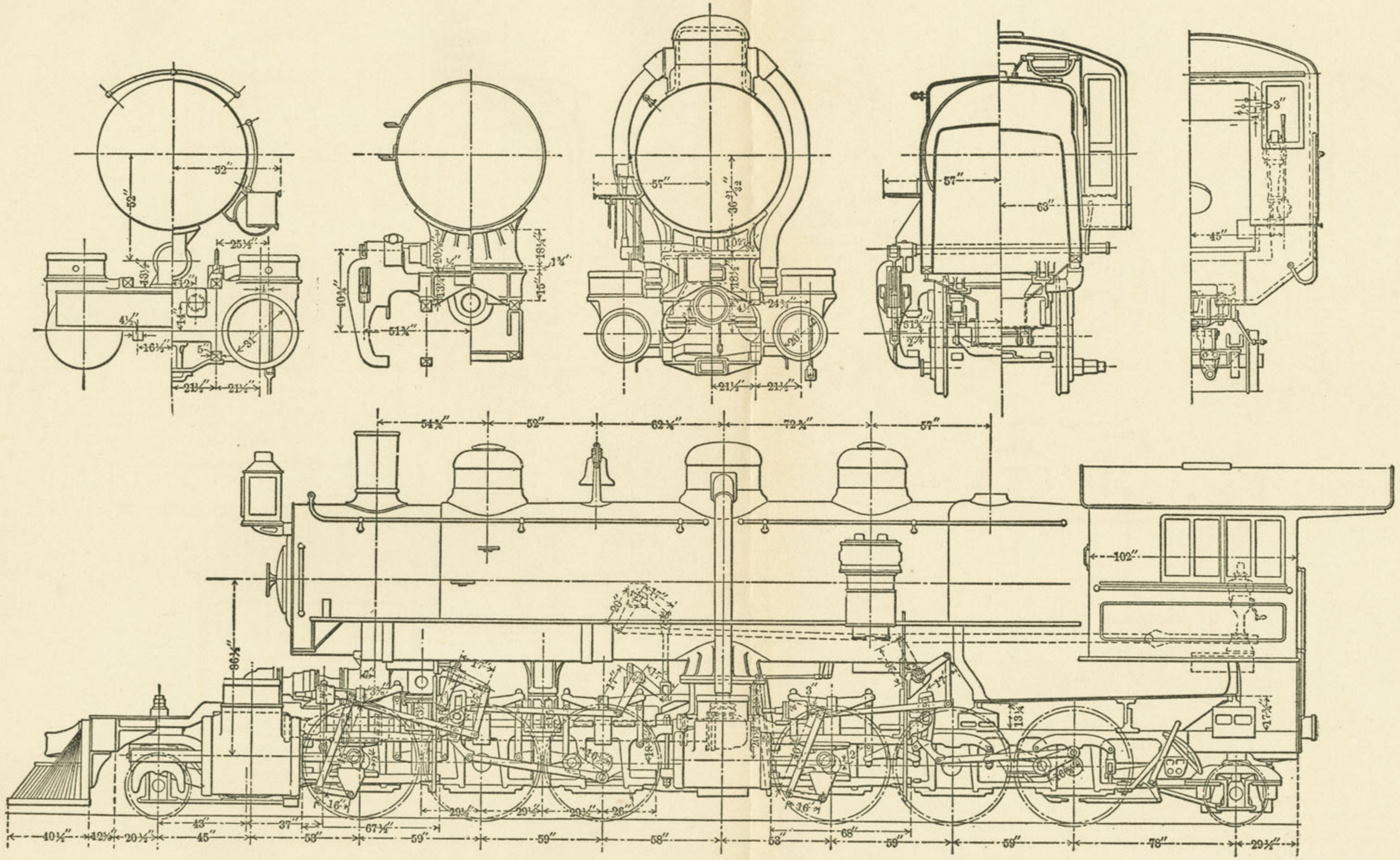


Fig. 13.

2-6-6-2 Type Mallet Compound Locomotive Used for Regular Freight Service, Great Northern Railway.

carries the largest amount of weight has a self-adjusting sliding bearing, and is located between the third and fourth pairs of drivers. This bearing permits free movement in all directions in the horizontal plane, and also includes a safety connection, which prevents the frames from dropping away from the boiler in case of any derailment. There is also a similar safety connection provided at the front end of the boiler between the guide yoke casting and the exhaust pipe below. The other support between the boiler and frames is located between the second and third pairs of drivers, and consists of two vertical columns located just inside the frames, and fitted with ball joints at either end. The upper end takes a seat in projections on the casting fastened to the boiler, and the lower end seats in castings having one end hinged below a frame cross-tie across the lower rails.

The Mallet Articulated Compound Engine, or 2-6-6-2 Type, Used on the Great Northern R. R. Two other designs of the same type have been brought out in this country, both being for the Great Northern Railroad, one designed for pushing service and the other for regular road service. They were built by the Baldwin Locomotive Works. These engines, however, differ from the two designs just mentioned in having two-wheeled trucks front and rear, making them of the 2-6-6-2 type, as shown in Fig. 13. While they have been in service a comparatively short time, the evidence is sufficient to show that they are successful for the service in which they are used.

The Twelve-wheel, or 4-8-0 Type. This type of engine is also considerably used for freight service, particularly on the Norfolk & Western Railway. Both the Walschaert and Stephenson valve motions are used with this type.

The average proportion of weight on the drivers of a twelve-wheel locomotive is 81 per cent. Comparing this with the Consolidation type, it is found that the twelve-wheel type has 8 per cent less weight on the drivers than the Consolidation type, which utilizes 89 per cent; so that on roads which have a suitable line for the operation of Consolidation locomotives the Consolidation type has the decided advantage. In comparing the two types, it should not be forgotten that the twelve-wheel type permits a longer boiler and longer flues, which allows the same amount of heating surface to be obtained with a smaller number of flues and wider bridges.

The twelve-wheel types of locomotives used on the Norfolk & Western Railway, shown in Fig. 14, weigh 204,000 pounds, of

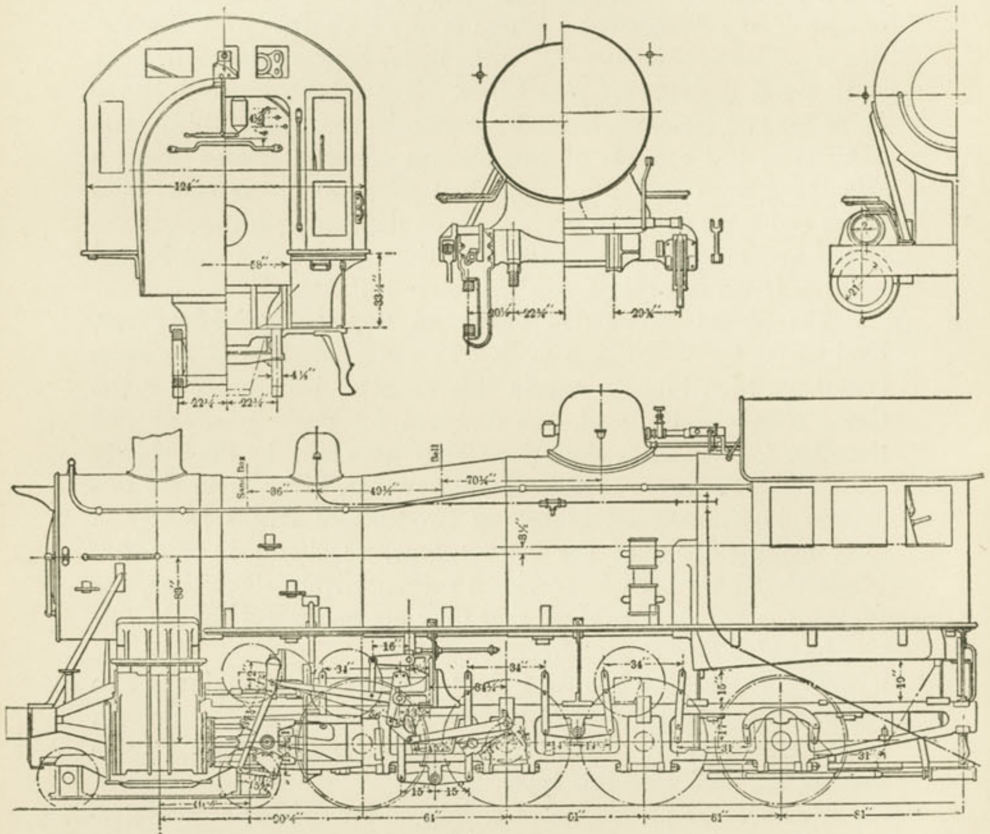


Fig. 14.

TWELVE WHEEL OR 4-8-0 TYPE FREIGHT LOCOMOTIVE USED ON THE NORFOLK & WESTERN RAILWAY.

which 165,800 pounds are on the drivers. The locomotives are arranged with a continuous driving equalization on each side, and the second pair of wheels, being the main drivers, are fitted with

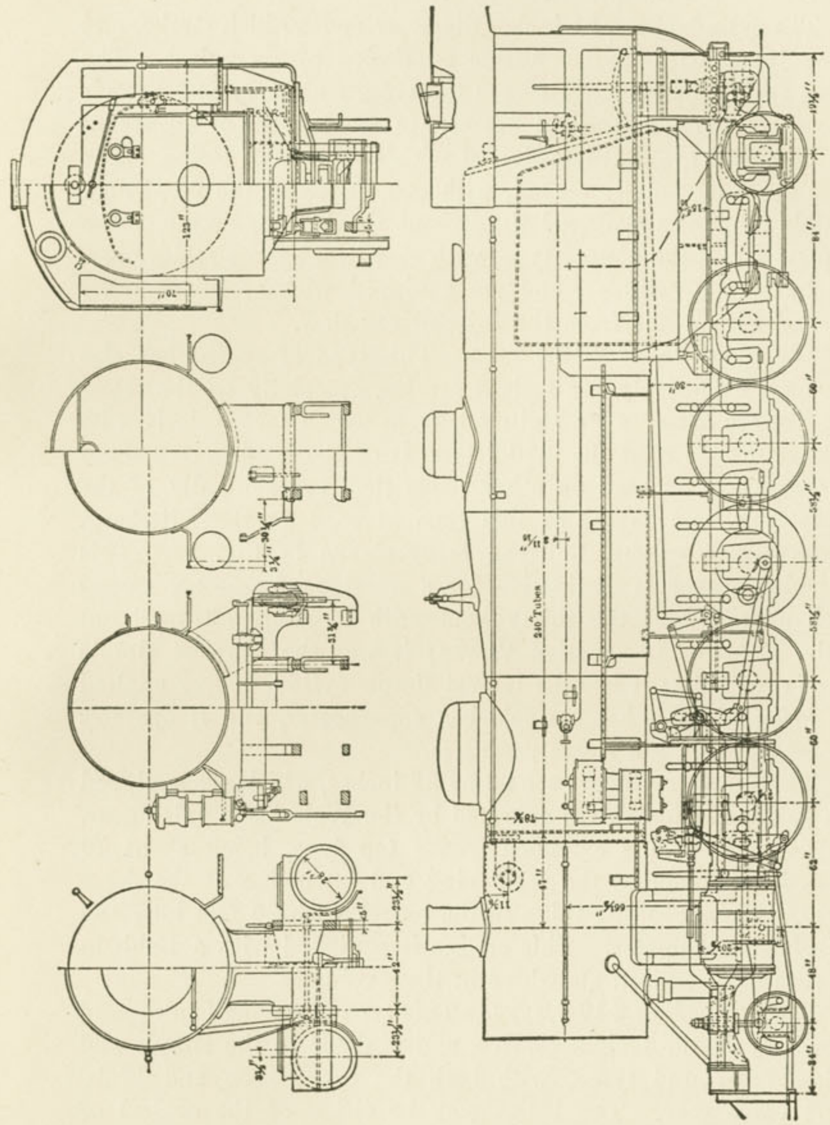


Fig. 15.

SANTA FE OR 2-10-2 TYPE OF FREIGHT LOCOMOTIVE USED ON THE PITTSBURG, SHAWMUT & NORTHERN R. R.

plain tires, the others being flanged. The main wheels have cast steel centers and the others cast iron.

The cylinders are 21 inches diameter and 30-inch stroke, and are equipped with 12-inch inside admission piston valves. The boilers are of the extended wagon top type, and carry 200 pounds pressure. The longitudinal seams are welded for 9 inches at each end, and are sextuple-riveted with double welt strips. The crown sheet is radially stayed, with one T-iron at the front end. Flexible stay-bolts are used throughout the breakage zone. The ash-pans are of the hopper type, with cast iron bottom slides operated by an air cylinder, and are equipped with sprinkler pipes supplied with water from the injector overflow.

The Santa Fe, or 2-10-2 Type. This type of engine has also been used extensively for freight service, especially on the Atchison, Topeka & Santa Fe Railroad, from which fact it derives its name. On this road the 2-10-2 type is of the tandem-compound construction. As used on other roads they are generally of the simple type, one engine of this type as used on the Pittsburg, Shawmut & Northern Railroad being shown in Fig. 15. This particular engine is distinctive for a number of reasons, among which are: it was the thirty-thousandth locomotive turned out by the Baldwin Locomotive Works; it was the heaviest simple engine ever built; it has the largest simple cylinders ever applied to a locomotive; it has a smoke-box superheater, and it operates at comparatively low steam pressures.

The simple cylinders are 28 by 32 inches, which are equipped with balanced slide valves operated by the Walschaert valve gear. The boiler is of the extended wagon top type, being about 79 inches in diameter at the front ring and 86 inches at the dome course. There are 391 tubes in the barrel, each 20 feet long and 2½ inches in diameter. This engine is equipped with a Baldwin superheater, described elsewhere in these volumes.

The Decapod, or 2-10-0 Type. This type of engine is also used extensively in the freight service, and is made in the simple and tandem compound types, with both the Stephenson and Walschaert valve gear. The boiler may be either of the conical or wagon top type. A recent type of Decapod engine used on the Buffalo, Rochester & Pittsburg Railroad is shown in Fig. 16.

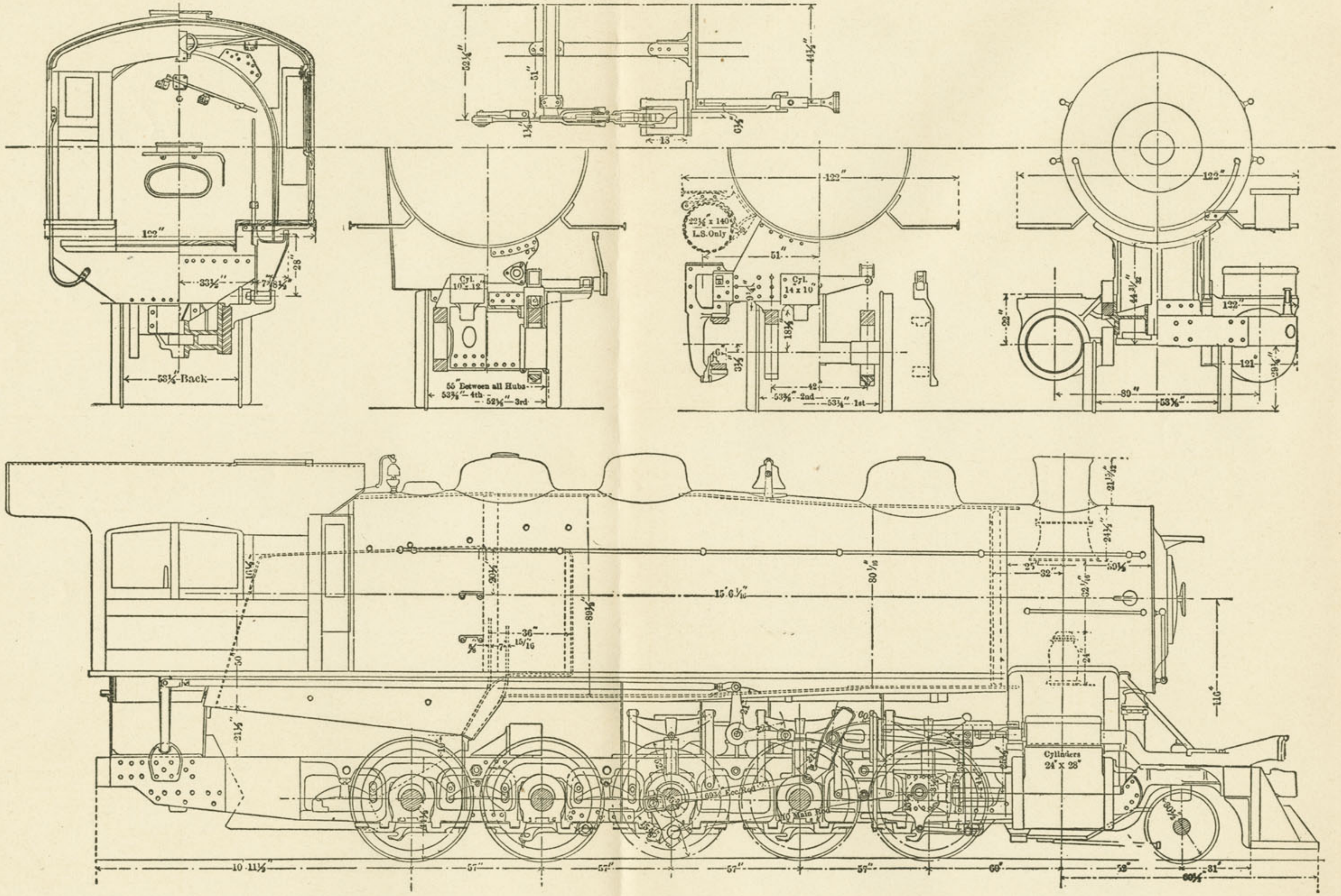


Fig. 16.

Decapod Locomotive Used on the Buffalo, Rochester and Pittsburg Railroad.

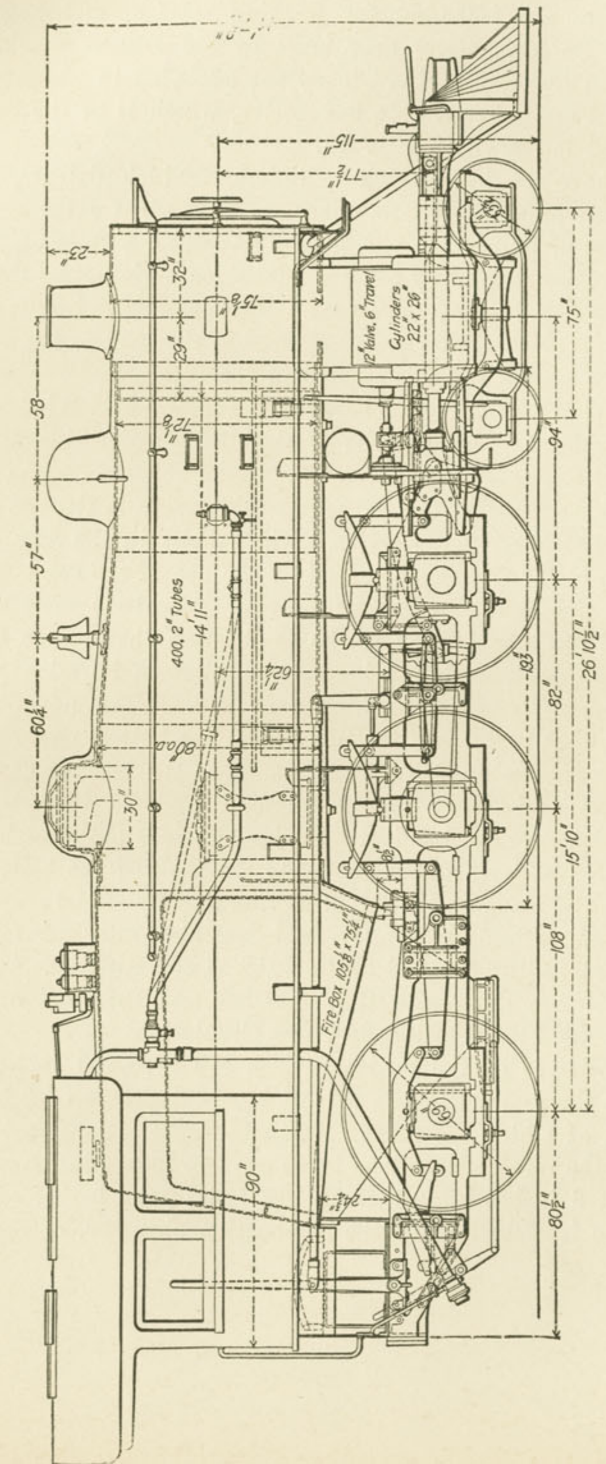


Fig. 17.

Side Elevation of Ten Wheel Type Locomotive Used on N. Y. C. & H. R. R.

These engines are intended for pushing service, and are the heaviest simple locomotives ever built by the Brooks Works of the American Locomotive Co. They are exceeded in weight and power by but one other simple locomotive, which is of the Santa Fe type, and is shown in Fig. 15.

They have 24 by 28-inch cylinders, 52-inch drivers, and carry a steam pressure of 210 pounds. This gives a theoretical tractive effort of 55,350 pounds, giving an adhesive ratio of 4.48. The steam is distributed by outside admission slide valves driven by the Walschaert type of valve gear. The valve gear link is supported by a special shaped casting secured to the back of the guide yoke, and the reverse shaft is carried in bearings bolted to the top of a cast steel cross tie located between the second and third pairs of driving-wheels. This permits of the direct connection of the reverse shaft arm with the radius bar.

One of the interesting features of this design is the use of a combustion chamber in the boiler. The results in the way of a reduction in boiler troubles obtained by the use of the combustion chamber on the Northern Pacific Railway have been most satisfactory, and the introduction of the combustion chamber in these engines shows evidence of an increasing belief in its advantages for wide fire-box engines burning soft coal. The advantages claimed are, that it removes the tubes from the hottest part of the fire, thereby decreasing flue leakage; adds to the heating surface of the fire-box; and gives a largely increased fire-box volume, which tends towards better combustion. In these engines the combustion chamber is 3 feet long and is stayed to the shell of the boiler by radial and sling stays on the upper section and by radial stays on the sides and bottom, bracing rods being also attached to the bottom and extending forward to the waist to add stiffness. Ample clearance between the combustion chamber and the shell of the boiler is provided to furnish good water circulation.

The boiler is of the conical wagon top type, 80 inches in diameter at the front, and has a total heating surface of 3,535.5 square feet, of which the tubes contribute 3,280 square feet and the fire-box the remainder. The tubes are two inches in diameter, and 15 feet 6 inches long, there being 404 in the barrel of the boiler. The introduction of the combustion chamber, of course, reduces the amount of tube heating surface. But the experience of the Northern Pacific Railway indicates that the increase in fire-box heating surface more than offsets this loss, it being found that engines with combustion chamber and less actual heating surface steam fully as well as those without combustion chamber and more heating surface.

The Mikado, or 2-8-2 Type. This type of engine is also extensively used for freight service, particularly on the Northern Pacific Railroad. It is made in both the simple and tandem compound types, with either the Stephenson or Walschaert valve gear. The boiler is usually of the extended wagon-top type.

Ten-wheel, or 4-6-0 Type. The 4-6-0 is a most excellent type for what is known as fast freight service, involving trains of moderate weight and high speed. Although the 2-8-0, or Consolidation type, is sometimes used in this class of service, the 4-6-0 type, as shown in Figs. 17 and 18, with the same number of wheels and a greater capacity for high speed, is usually considered the better type for such traffic. With driving-wheels from 63 to 69 inches in diameter, the 4-6-0 locomotive may be used interchangeably in fast freight and passenger service, and this type is, therefore, sometimes referred to as the " All-round " type.

Before the introduction of the 4-6-2, or Pacific type, the 4-6-0, or Ten Wheel type, was more generally used than any other for heavy and fast passenger service. Passenger traffic which requires a tractive effort of six-coupled driving-wheels and demands a boiler capacity that cannot be provided on ten wheels requires the 4-6-2 type. But there yet remains a relatively large field for the 4-6-0 type in passenger service where the steam requirements are not too great. The 4-6-0 provides a greater hauling capacity in proportion to the total weight than the 4-6-2 type, and, for this reason, it is a more economical and efficient type for passenger service where conditions do not require the greatest capacity for sustained speed.

In a large measure the diameter of the driving-wheels becomes a limitation to the 4-6-0 type in passenger service, because, with driving-wheels over 73 inches in diameter, this type does not lend itself readily to a design of deep fire-box other than one placed between the driving-wheels. In many cases, however, 4-6-0 loco-

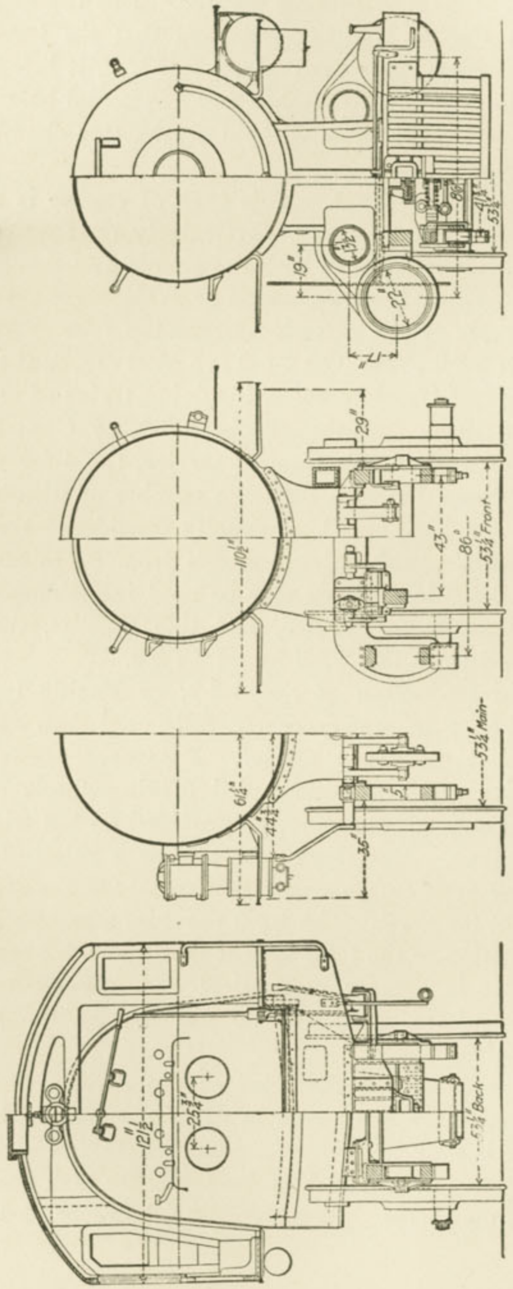


Fig. 18.

SECTIONS AND END ELEVATIONS OF TEN WHEEL TYPE LOCOMOTIVE USED ON N. Y. C. & H. R. R.

motives have been built with wide fire-boxes over driving-wheels of 69 inches diameter. When the fire-box is carried over the driving-wheels, a sufficient depth of throat sheet for ordinary conditions is secured by sloping the mud-ring downward towards the front end between the second and third pairs of driving-wheels. The 4-6-0 lends itself readily to a Wooten type of fire-box, and is the favorite type of heavy passenger engine where anthracite coal is used as fuel.

Locomotives of this type have been built in designs ranging in weight from 60,000 to 200,000 pounds, with hauling capacities adapted to a variety of road and service conditions.

The Chicago and Northwestern Railway uses the simple ten-wheel type exclusively for freight service, and the locomotive equipment of this road differs from every other large railroad in the country in that it does not have any locomotives of the Consolidation type. The work usually performed by the Consolidation locomotive is taken care of on this road by ten-wheelers, most of which are equipped with the Stephenson link, although the later types are equipped with the Walschaert valve gear. A large number of other roads use the ten-wheel locomotive for heavy passenger and fast freight service.

Mogul, or 2-6-0 Type. Before the increasing requirements of heavy freight service resulted in the development of the 2-8-0, or Consolidation type, the 2-6-0, or Mogul type, as shown in Figs. 19 and 20, was more generally used than any other in this class of service.

In selecting the type of locomotive for any service, it is profitable, from the standpoint of economy of repairs, to use the minimum number of driving-wheels possible within the limits of the necessary tractive power. Although for freight service, involving the hauling of very heavy trains on steep grades, the 2-8-0, or Consolidation, type is required, there is a large field for the Mogul type in freight service where the requirements are not too severe. For freight service on comparatively level roads or on heavy rails, where a large load per axle is permitted, sufficient hauling capacity may be provided in this type to meet ordinary requirements. While not generally recommended for what may be called fast freight service, this type is sometimes used in this

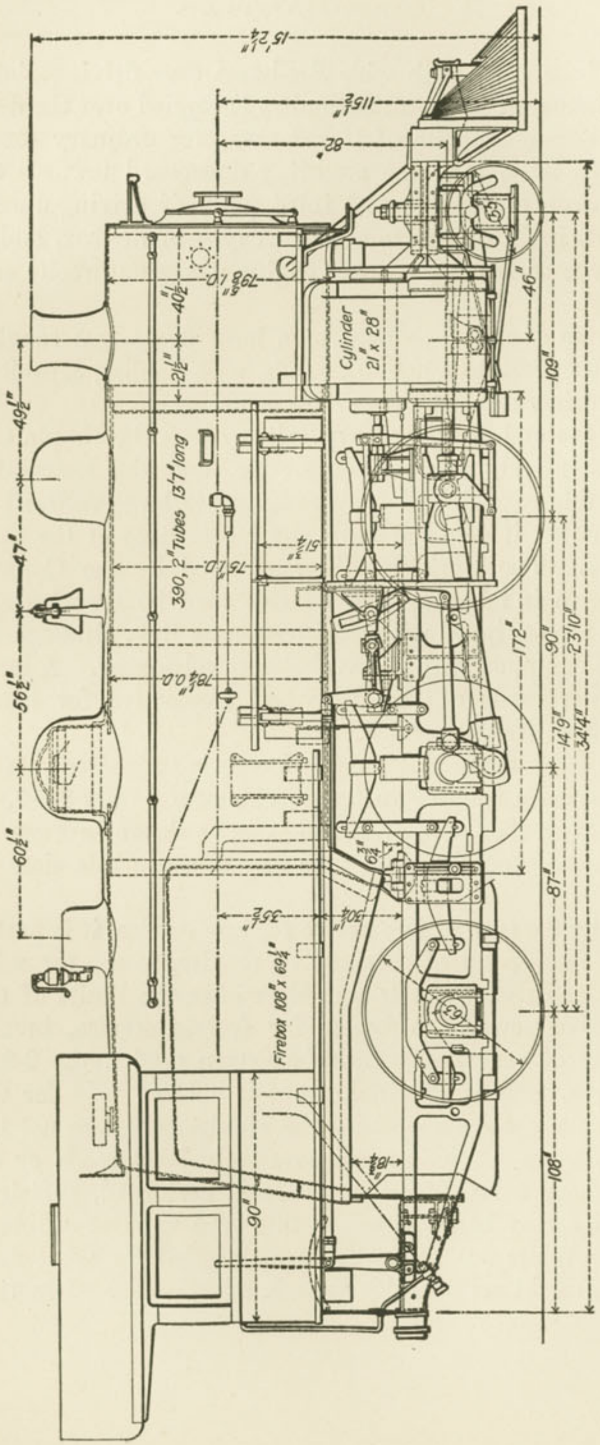


Fig. 19.

SIDE ELEVATION OF MOGUL TYPE FREIGHT LOCOMOTIVE USED ON THE VANDALIA LINE.
(*American Locomotive Company.*)

class of service, and many Mogul locomotives are successfully hauling such trains.

The 2-6-0 wheel arrangement provides a two-wheel leading truck with good guiding qualities, and places a large percentage of the total weight on the driving-wheels. A large number of locomotives of this type show an average of 87½ per cent. of the total weight effective for adhesion.

Boilers with sufficient capacity for moderate speeds may be provided in this type, and, with relatively small diameter of driving-wheels, it lends itself readily to wide variations in grates and fire-boxes. When necessary, the fire-box may be placed over the driving-wheels in order to obtain ample grate area for any kind of fuel. By sloping the fire-box down at the front end between the second and third pairs of driving wheels, sufficient depth of throat-sheet may be obtained for ordinary conditions.

Locomotives of this type have been built in designs ranging in weight from 32,000 to 187,000 pounds, and with hauling capacities adapted for a great variety of road and service conditions. The Vandalia Lines use Mogul locomotives which are the heaviest of their types built.

The Prairie, or 2-6-2 Type for Freight Service. The Prairie type is a favorite on some roads for freight service, particularly the Wabash Railroad, on which are a number with 70-inch drivers, as shown in Fig. 21, and intended for high speed freight service, and a number with 64-inch drivers for low speed freight service. In all other respects, except the diameter of the front truck wheels, the two classes are alike. The high speed engines have a tractive effort of 32,900 lbs., and the low speed 36,000 lbs.

This type is a development of the Mogul type, and it allows a large boiler capacity, larger cylinders and grate area. It gives large adhesive weight, and the trailing wheels allow wide and deep fire-boxes. As used on the Wabash locomotives, the boiler is of the extended wagon-top type, 70 inches outside diameter at the front flue sheet, and 79½ inches at the connection to the fire-box. The front flue sheet is secured in a ring of 1-inch plate, to the interior of which is also fastened the front barrel sheet. The ⅝-inch smoke box sheet is riveted to the outside of this ring. The flue sheet is set 31 inches from the center line of the stack, and 71⅛

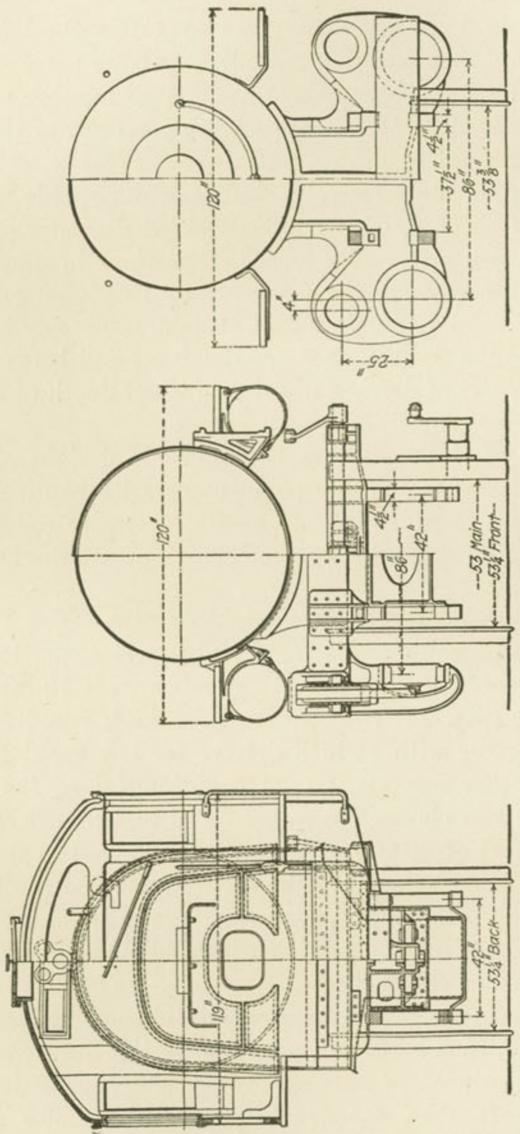


Fig. 20.

SECTIONS AND END ELEVATIONS OF MOGUL TYPE FREIGHT LOCOMOTIVE USED ON THE VANDALIA LINE.

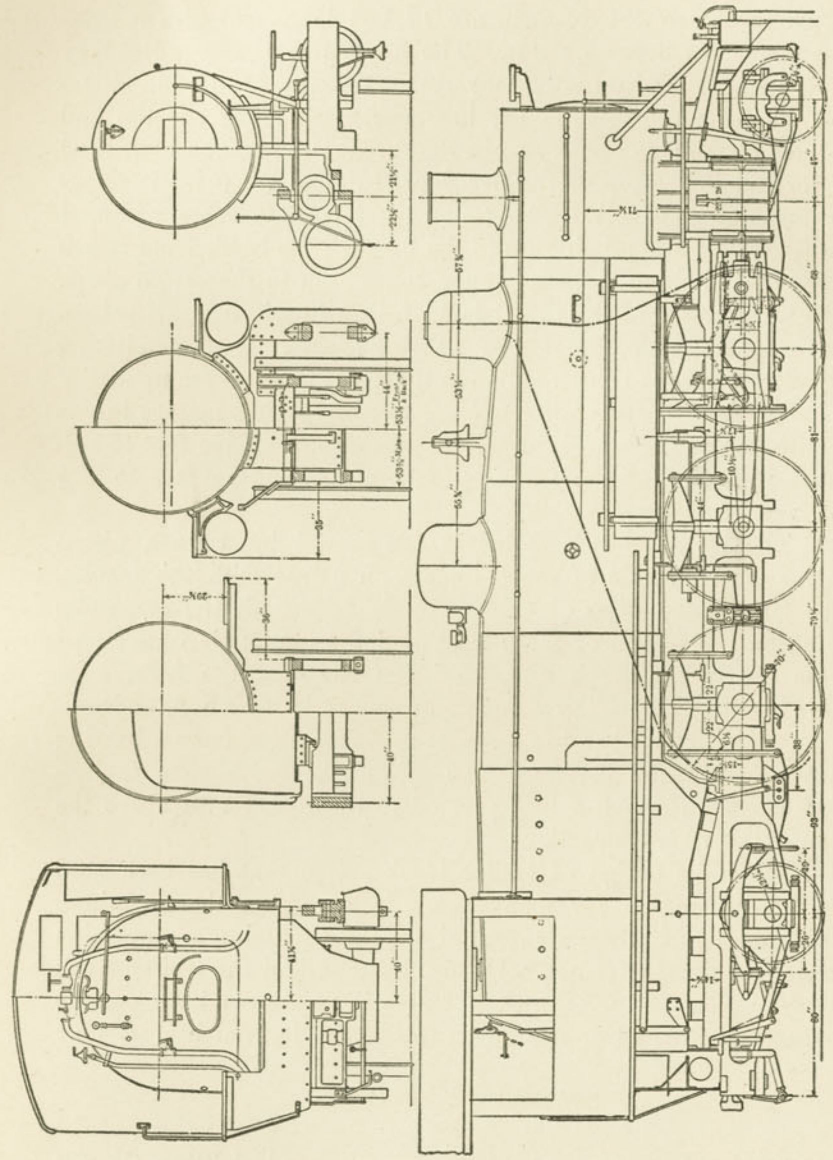


Fig. 21.

PRAIRIE TYPE OF FREIGHT LOCOMOTIVE USED ON THE WABASH RAILROAD.

inches from the forward end of the smoke box. The flues, of which there are 301 2¼-inch, are 19 feet long, and give a heating surface of 3,368.5 sq. ft. The fire-box is of the radial stay type, with one T-iron sling stay support at the front end. Flexible staybolts are used in the breakage zones along the top and corners of the side sheets and in the throat sheet. The back head is vertical to the top of the fire door, from which point it slopes inward quite sharply. The water leg is of the same width, 4 inches from the mud ring up to the band in the head, from which point it spreads to 9 inches at the connection to the crown sheet. The water space in the throat is 4½ inches in width at all points. The single fire door measures 14 x 28 inches. Two non-lifting injectors feeding to check valves in the usual location are used.

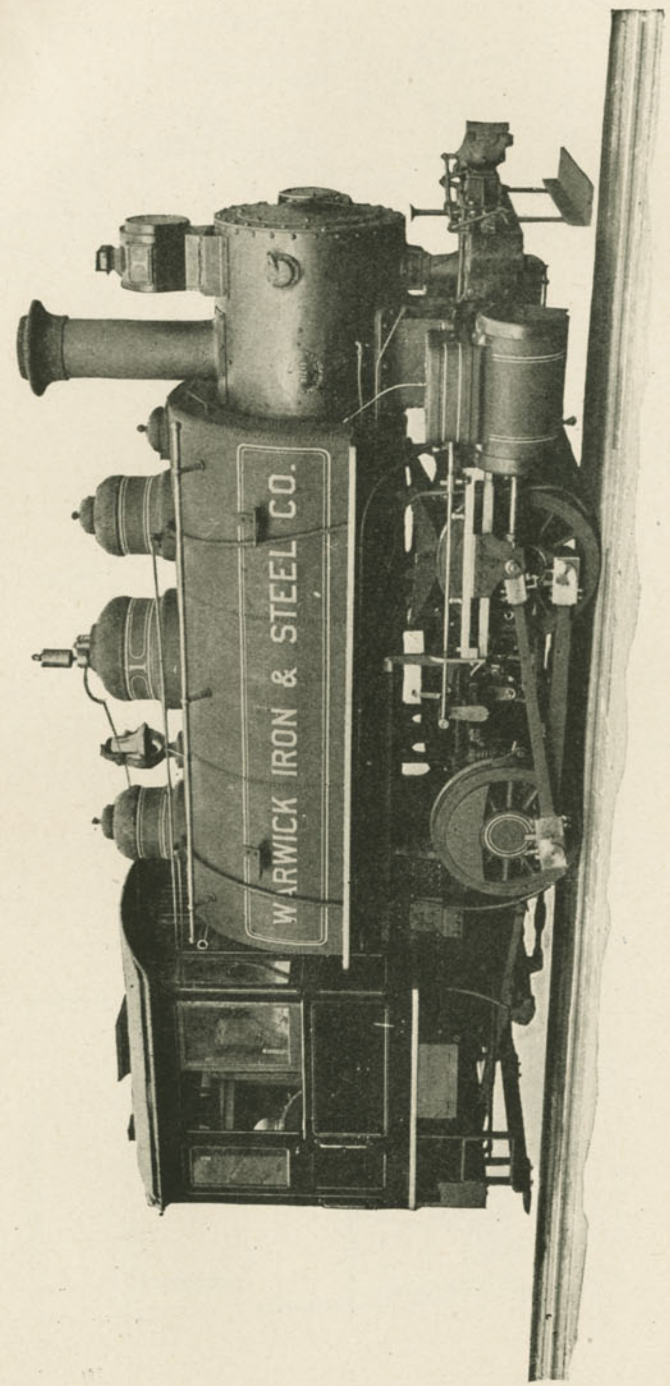
The boiler ratios allow 65½ sq. feet of heating surface to one square foot of grate area, and 288 sq. feet to one cubic foot of cylinder volume. There is one sq. foot of heating surface to 42½ lbs. weight on drivers.

The 22 x 28-inch cylinders are served by 12-inch piston valves placed inside of the cylinders on a line with the frames. The Stephenson type of valve gear is employed, the eccentrics being on the second or main axle, and the motion is transferred from the link through a transmission bar over the front axle. This bar is supported by a double hanger at its rear end, and connects at the forward end to a rocker arm supported from a bearing secured below the bottom frame rail. The valve stem connection is made through a link pivoted to the rocker arm above the transmission bar connection.

The same design of trailer truck frame that has been used on the Burlington for many years is found on these engines. This consists of a heavy cast steel cross-bar forming a conneetion between the main frames, set 45-in. centers, and the trailer truck frames set at 80-in. centers. The trailing wheels have outside journals, the equalizer resting on top of the journal box.

SWITCHING ENGINES.

Locomotives for switching, shunting and drilling do not usually have any front trucks, and are usually of the 0-4-0, 0-6-0,



FOUR WHEEL SADDLE TANK LOCOMOTIVE USED FOR SWITCHING
(Baldwin Locomotive Works)

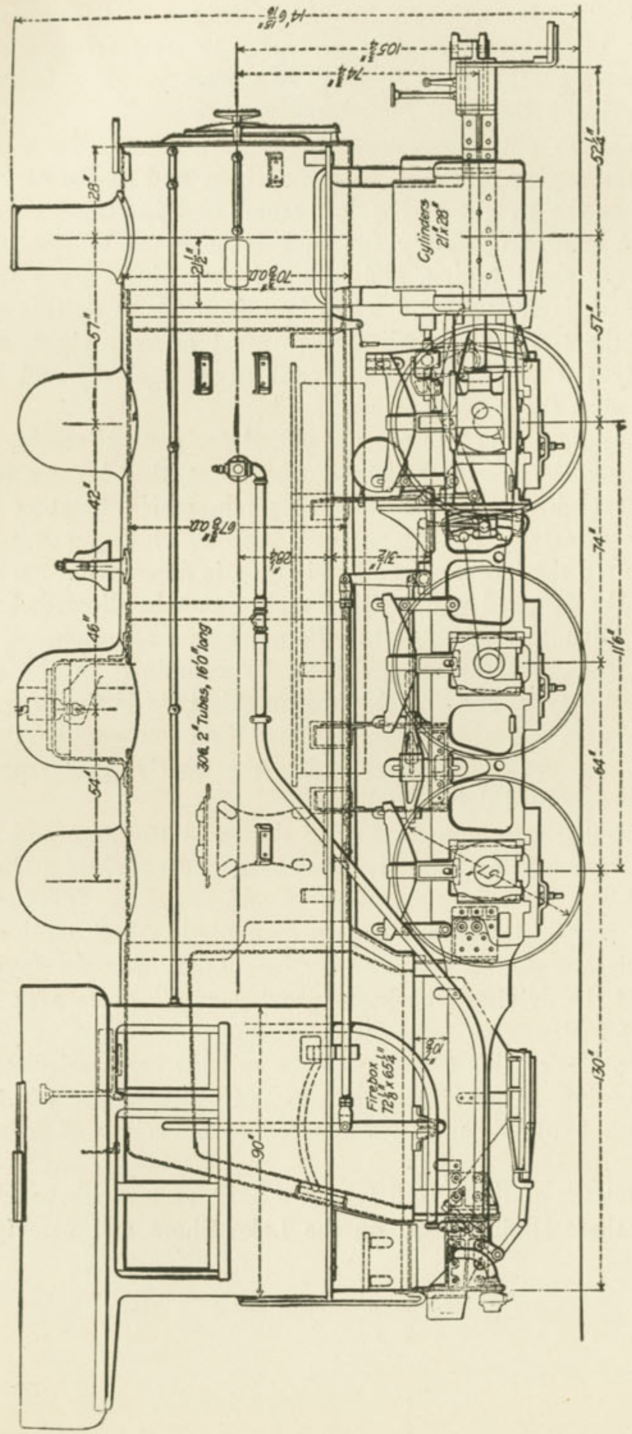


Fig. 22.

Side Elevation of Six Wheel Type Switching Locomotive Used on the New York Central.

0-8-0 or 0-10-0 types. These types of engines are used for switching because in such service it is necessary to start trains often, and therefore a great deal of adhesion is necessary. For the very heaviest service Articulated Mallet engines are used.

In order to obtain considerable traction effort, the whole weight of the engine is placed on the drivers, and in the case of small engines the weight of the water and fuel is placed on the drivers. It is also necessary for such locomotives to run over curves of very short radius, and into switches whose angle with the main track is very great. Therefore, in order to do this and remain on the track, their wheel-bases must be very short, and consequently the wheels are all placed near together, and are usually between the smoke-box and fire-box.

These types of engines are not suited for general traffic, because, owing to the shortness of their wheel-base, they become very unsteady at high speed, and start to pitch, which becomes decidedly uncomfortable for the engineer, and which may cause the engine to jump the track. As all switching is done at low speeds, the use of the forward and trailing trucks may be discarded for the greater advantage of obtaining the maximum adhesion.

These factors are most satisfactorily combined in the six-wheel, or 0-6-0 type, and for this reason this type is the favorite for switching service which requires more than four-coupled driving wheels, and yet which comes within the tractive power possibilities of six-coupled driving wheels.

The 0-6-0 wheel arrangement, as shown in Figs. 22 and 23, places all the weight on the driving wheels, and provides a short, rigid wheel-base for running over frogs and switches. This type lends itself readily to the application of a fire-box both wide and deep. If necessary, the fire-box may be carried over the frames and back of the driving wheels, to provide ample grate area for any kind of fuel.

Locomotives of this type have been built in very satisfactory designs, ranging in weights from 39,000 pounds to 176,500 pounds, with hauling capacities adapted to a variety of service conditions.

Locomotives of the 0-10-0 type are built very much heavier. A type of these engines used on the Lake Shore and Michigan

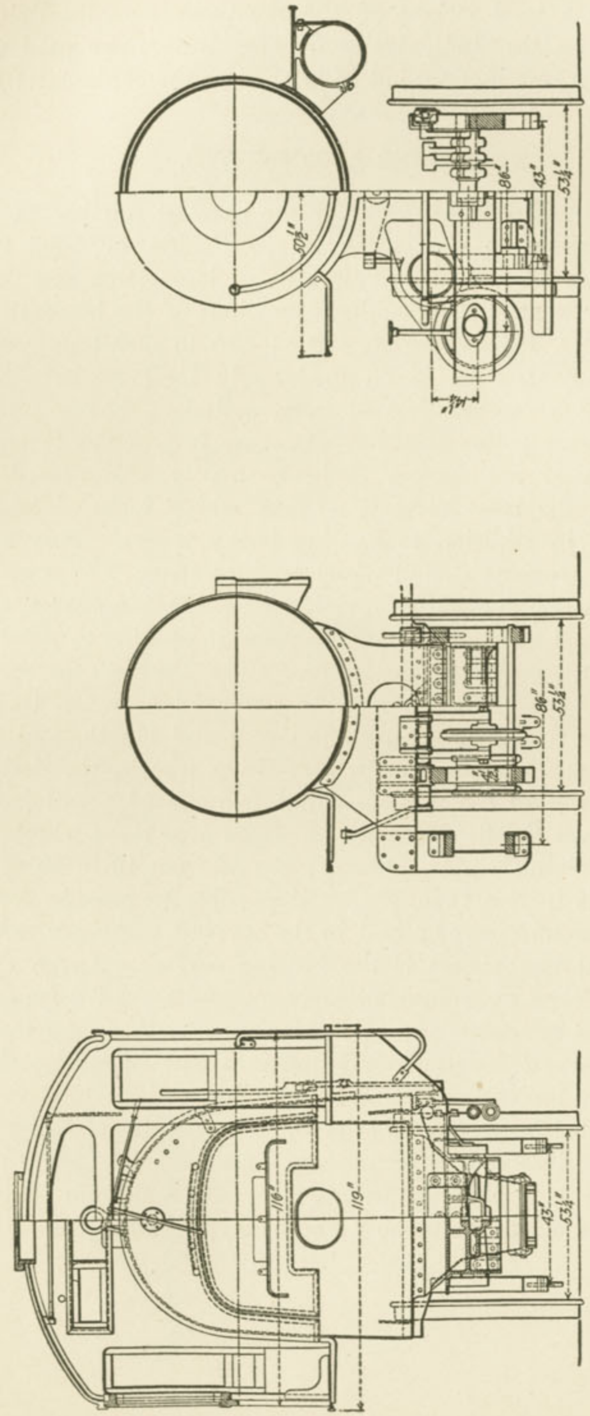


Fig. 23.

Sections and End Elevations of Six Wheel Type Switching Locomotive Used on the New York Central.

Southern has a total weight of 270,000 pounds on the drivers. Wagon top, straight, Bellpaire or Wooten boilers are used with the Stephenson link motion, but in large sizes the Walschaert gear is being used.

PASSENGER LOCOMOTIVES.

Pacific, or 4-6-2 Type. By far the greatest number of passenger locomotives in use belong to the Pacific, or 4-6-2 type, shown in Figs. 24 and 25. This type of locomotive was developed in order to meet the exacting conditions of the heaviest passenger service. Trains weighing from 500 to 600 tons require exceptional power, even if on moderately level roads. Such trains require a combination of large cylinders, heavy tractive weight and large boiler capacity. Because it provides this combination in very satisfactory designs, this type is remarkably successful in the most difficult service, which includes heating and lighting, in addition to hauling heavy trains. This wheel arrangement provides a four-wheel leading truck with excellent guiding qualities; six-coupled driving wheels, giving large adhesive weight, and trailing wheels, rendering it possible to provide a suitable fire-box and large grate area. The Pacific type readily provides for such grate areas to be arranged over the trailing wheels in the fire-boxes of suitable depth and length, and with ample water spaces. In fact, with trailing wheels, the designer has a free hand in the most essential features of a satisfactory fire-box, because the fire-box may be placed over these wheels and back of the driving wheels. Grate areas of from 40 to 50 square feet, available in this type, render it possible to provide for the large fuel consumption required in the severest passenger service.

Of equal importance is the heating surface. Large cylinders require large steam-making capacity, and the 4-6-2 type provides the least restrictions also in this respect. A comparison of a number of typical passenger locomotives now in service shows that the 4-6-2 has home heating surface for a given total weight than is provided for in any other type. Two designs of heavy passenger locomotives of this type were first used in 1902 on the Missouri Pacific Railway and the Chesapeake and Ohio Railway. To these locomotives the name "Pacific Type" was given.

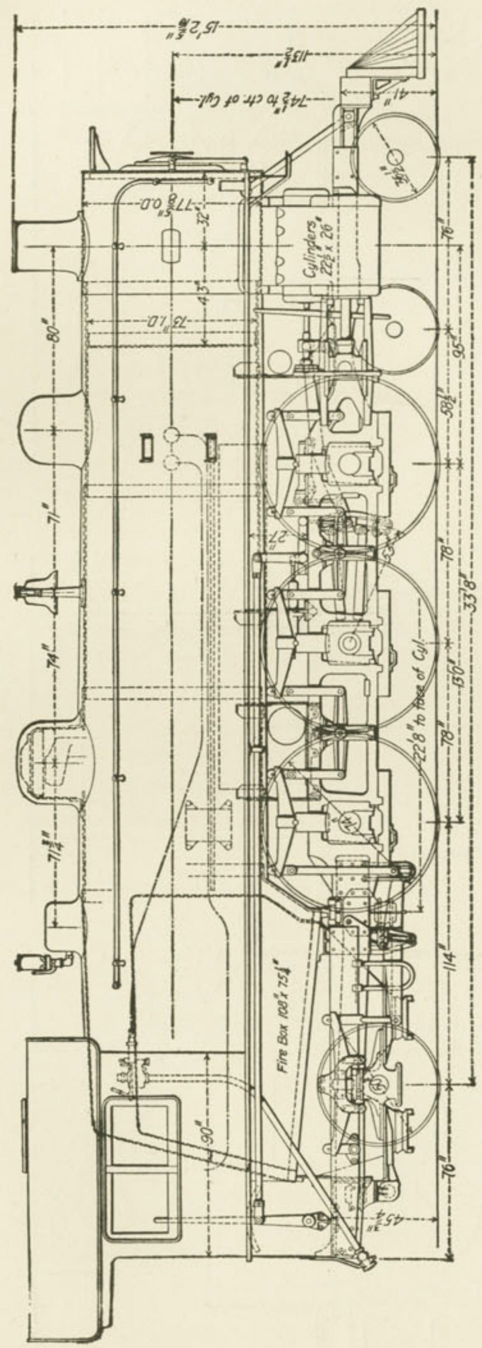


Fig. 24.

Side Elevation of Pacific Type Passenger Locomotive Used on the Erie R. R.

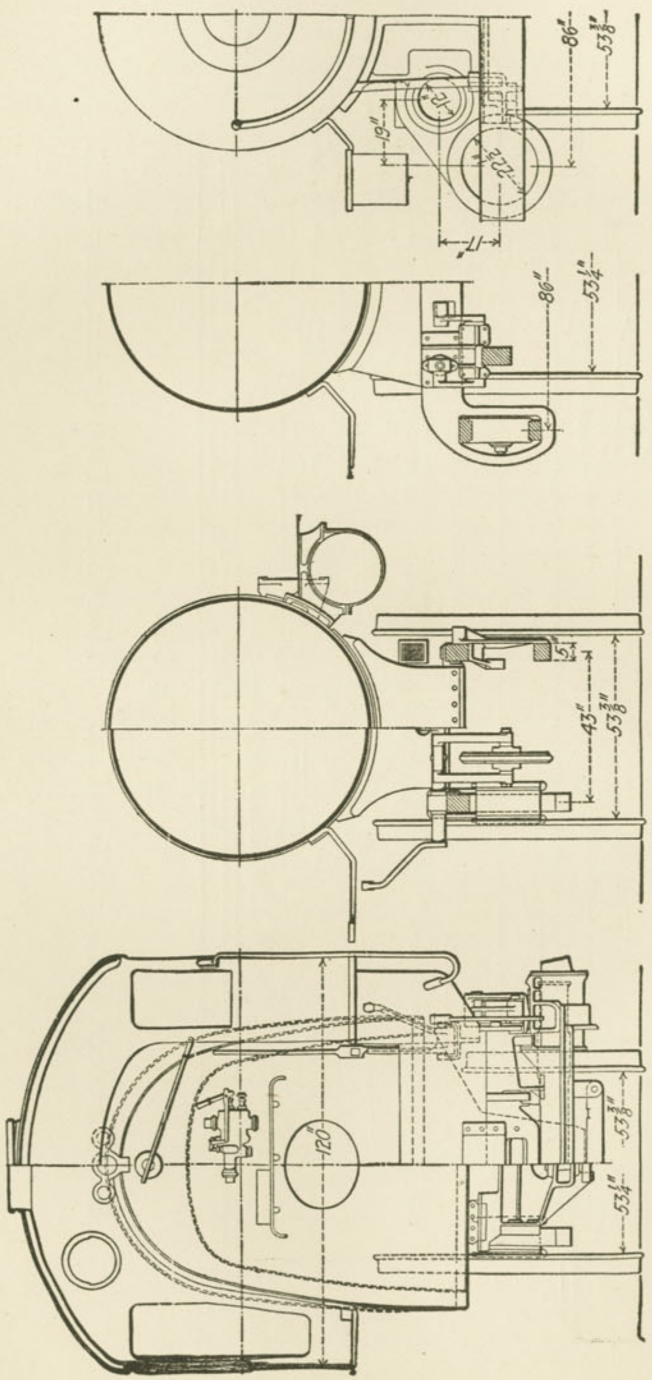


Fig. 25.

SECTIONS AND END ELEVATIONS OF PACIFIC TYPE PASSENGER LOCOMOTIVE USED ON THE ERIE R. R.

Weight on drivers and cylinder power bear such relation to each other as to strongly influence the selection of types. For example, it is easy to see that the boiler which may be carried on a locomotive of the Consolidation, or 2-8-0, type would be very easily exhausted of steam if the locomotive should run at anything more than ordinary speeds. This type is adapted only to relatively slow service, because the cylinders are naturally made large as a result of the large amount of weight on the driving wheels. The Consolidation type has a large percentage of total weight on the drivers—it may have 90 per cent—and the Atlantic, or 4-4-2,

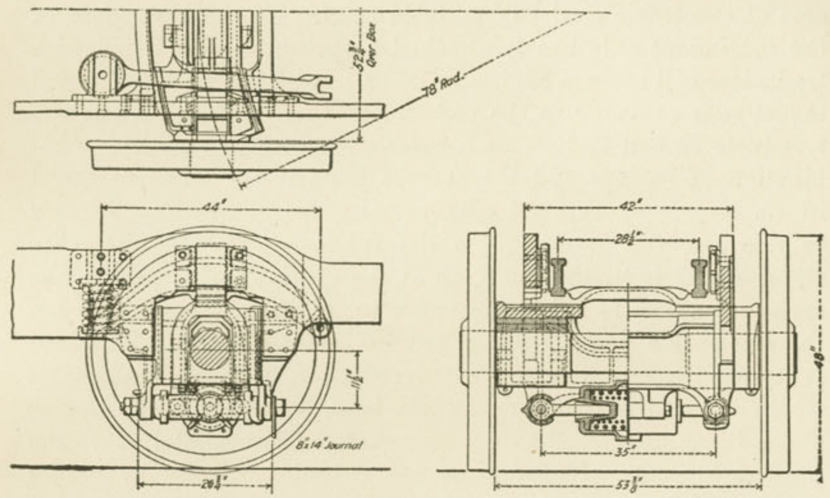


Fig. 26.

TRAILING TRUCK WITH INSIDE BEARINGS.

type represents the smallest percentage of total weight carried on drivers of all the types ordinarily used. Of fifty-eight examples of recent Atlantic type locomotives, the average proportion of total weight carried on the driving wheels is 50.4 per cent. Of twenty-six examples of the Pacific type, the average proportion is 61.2 per cent.

Trailing Trucks for Pacific Type Locomotives. Trailing trucks of two distinctly different types are used on the Pacific type engine, both of which are successful. The inside bearing truck, shown in Fig. 26, is the simpler and lighter of the two, but the outside bearings, however, give a wide supporting base at the rear of the locomotive, which contributes to good qualities. With outside bearings the brake hangers for the trailing wheels may be attached to the truck frame, so that they move with the wheels on curves. Outside bearings also have the advantages of accessibility for lubrication, examination and renewal of packing and for repairs, such as the renewal of springs and journal bearings.

Radial Truck with Inside Bearings. The radial truck with inside bearings at each end, shown in Fig. 26, is 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 fitted with transverse coil springs having followers, and fitted with horizontal thrust rods extended 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 its 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 position when the locomotive passes upon a tangent after 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 frame.

Radial Truck with Outside Bearings. The radial truck with outside bearings, shown in Fig. 27, has journal boxes rigidly attached to the frame, the forward rails of which converge to a point in which a pivot pin is centered. This 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 a letter U, at the center of which a spring housing 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 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.

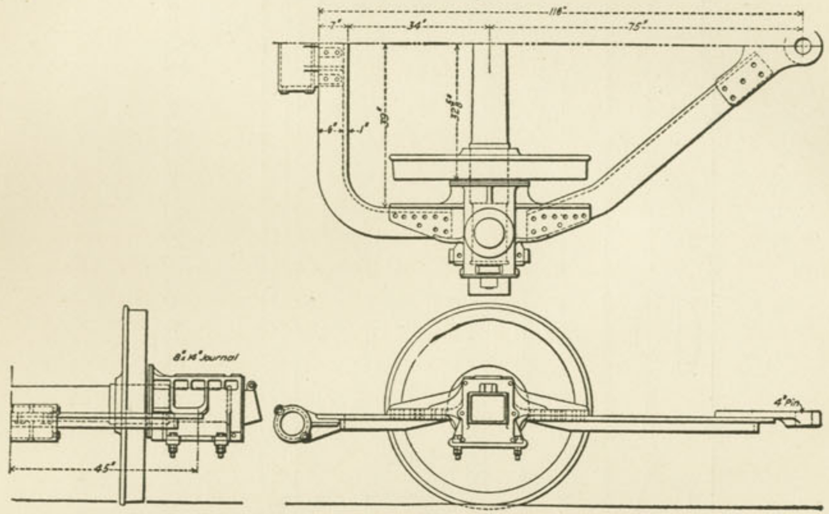


Fig. 27.

Trailing Truck with Outside Bearings.

The largest Pacific type of locomotive, which in point of size and weight exceeds any passenger locomotive ever constructed, is used on the Pennsylvania Railroad. It weighs 269,200 pounds, has 24 by 26-inch simple cylinders, a $79\frac{3}{4}$-inch boiler, 21 ft. tubes, 61.8 sq. ft. grate area, and carries 205 pounds steam pressure. The standard type of engine on the Pennsylvania Railroad for many years was the Atlantic type; but with the heavy trains and difficult grades the limit of tractive effort of the Atlantic type was reached. The accompanying table will give the weight and dimensions of a large number of other types of the Pacific locomotive used on 13 different railways.

Prairie, or 2-6-2 Type. The 2-6-2, or Prairie, type, Figs. 28 and 29, is the logical development of the 2-6-0, or Mogul, type, as

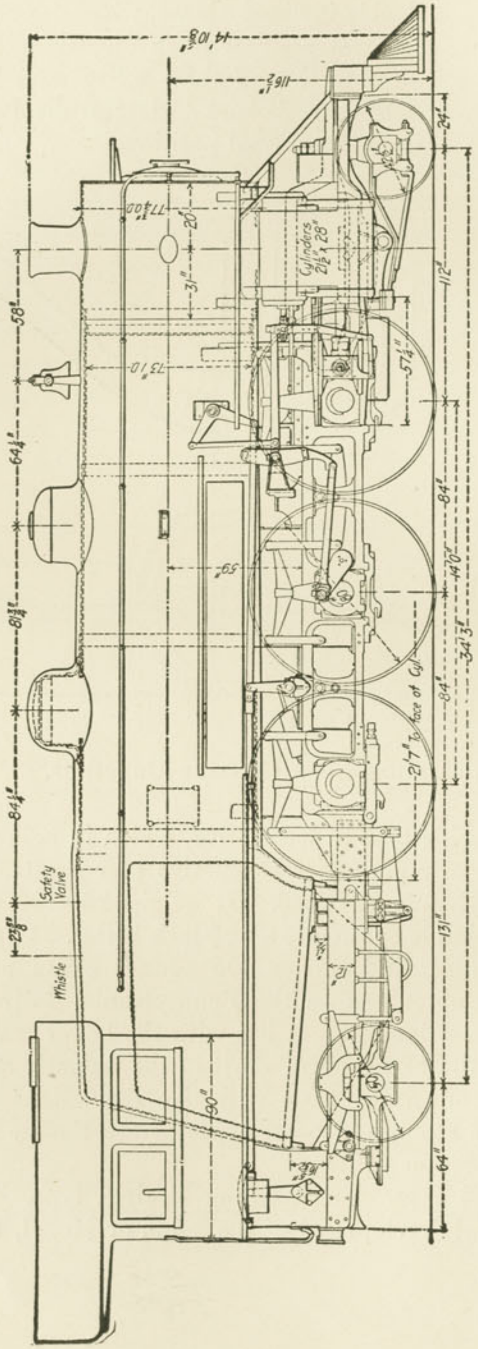


Fig. 28.

Side Elevation of Prairie Type Locomotive Used on Pennsylvania Lines.

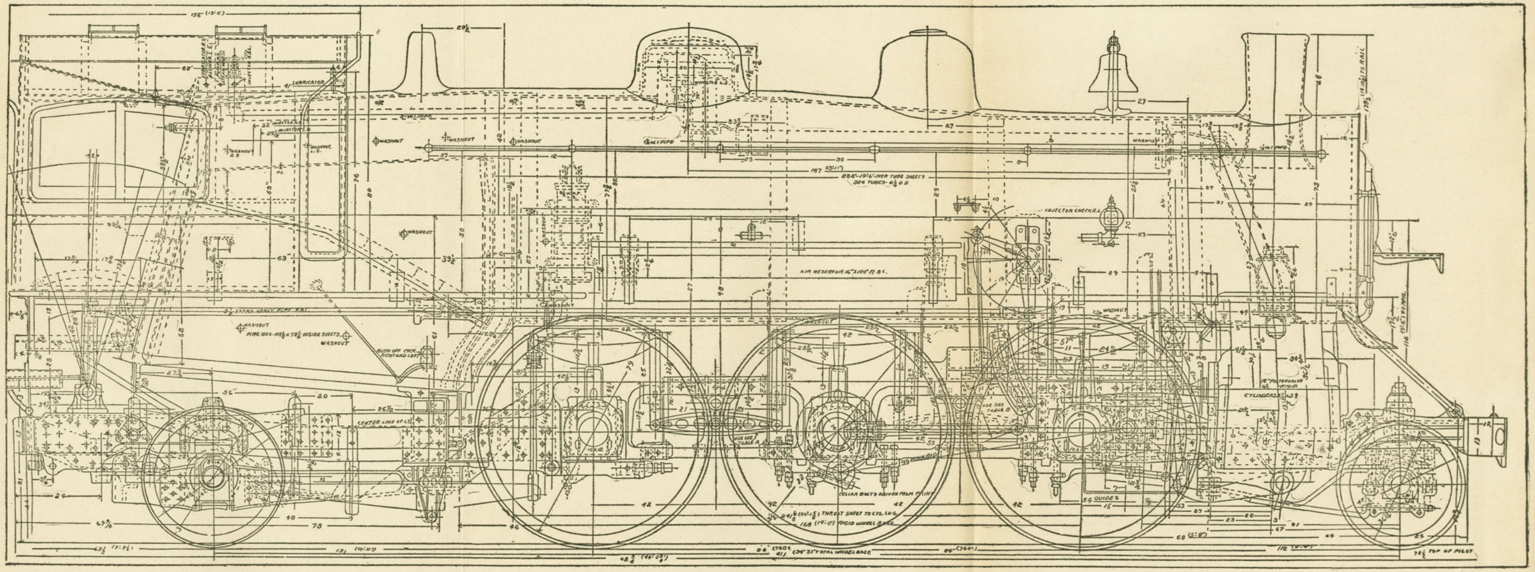


Fig. 30.
Longitudinal Section of Prairie, or 2-6-2 Type, L. S. & M. S. Fast Passenger Engine.

a result of modern passenger and fast freight service. Because of the opportunity afforded in this type to arrange designs which are very satisfactory in both these respects, the 2-6-2, or Prairie, type is exceedingly successful in both classes of service.

For hauling heavy trains at high rates of speed great steam-making capacity is required, and large heating surface and grate area must be provided. Not only must the boiler capacity be large, but large cylinders and heavy tractive weight are also required. These factors are very satisfactorily combined in the 2-6-2, or Prairie, type, and for this reason this type has reached a high degree of development in the severest passenger service.

This wheel arrangement provides a two-wheel leading truck with good qualities, six-coupled driving-wheels, giving large adhesive weight, and trailing wheels, rendering it possible to provide wide grate areas in fire-boxes of suitable depth. With the fire-box placed over the trailing wheels, this type lends itself readily to a most satisfactory design of wide fire-box, with ample depth at the front end, which is so particularly advantageous in bituminous coal-burning engines. One of the greatest advantages gained by the use of trailing wheels is the opportunity to provide a deep as well as wide fire-box.

The 2-6-2, or Prairie, type, is also a most satisfactory type for fast freight service, involving trains of moderate weight and high speed. With driving-wheels from 63 to 69 inches in diameter, this type is used interchangeably in either passenger or fast freight service. In short, it may be said that for service requiring the starting capacity of six-coupled driving-wheels and a larger boiler capacity than can be provided in the 2-6-0 or 4-6-0 types, the 2-6-2 is a most satisfactory type.

The 2-6-2 type of locomotive used on the Lake Shore & Michigan Southern Railway, and shown in Figs. 30 and 31, is a good example of the Prairie type which is used for hauling heavy trains at high speed. The engine is a simple one, with cylinders $21\frac{1}{2}$ by 28 inches, and driving wheels, which are made of cast steel, 79 inches in diameter. The tractive effort of the engine is 27,850 pounds. The total adhesive weight carried on the driving wheels is 165,000 pounds. The valve motion is of the Walschaert type, and operates piston valves 12 inches in diameter, having inside ad-

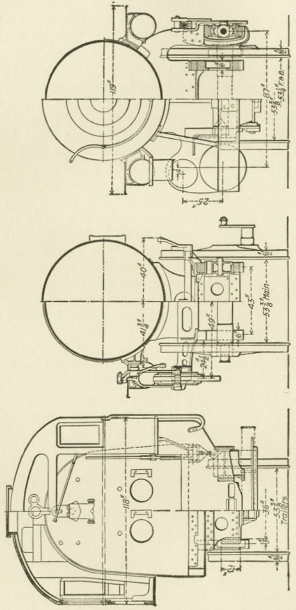


Fig. 29.

SECTIONS AND END ELEVATIONS OF PRAIRIE TYPE LOCOMOTIVE USED ON PENNSYLVANIA LINES.

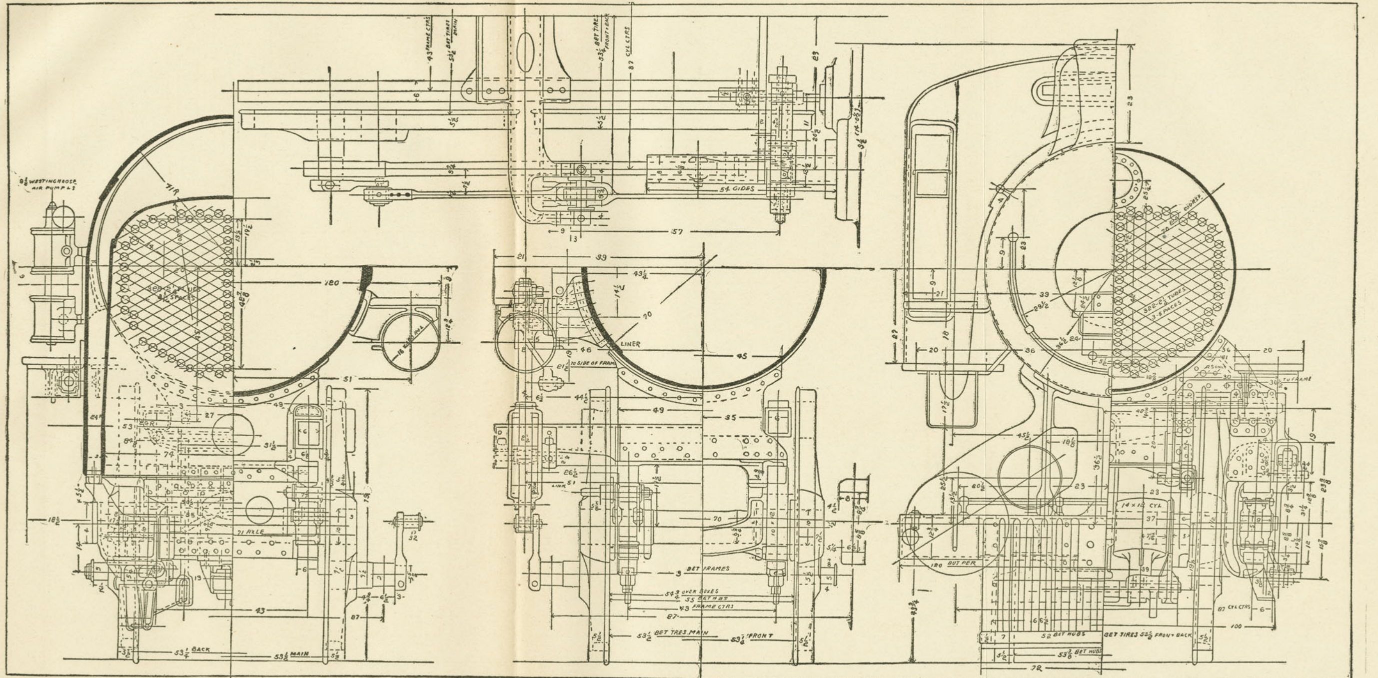


Fig. 31.—CROSS-SECTIONS SHOWING BOILER, FIRE-BOX, CYLINDERS, DRIVING WHEELS AND PLAN OF VALVE MOTION, L. S. & M. S. FAST PASSENGER ENGINE.

mission. The valves have a travel of $6\frac{3}{8}$ inches and exhaust clearance $\frac{1}{8}$ of an inch.

The driving wheels of this engine are spaced equally, being 84 inches apart. All wheels are flanged. The total wheel base of the engine is 34 feet 3 inches. The driving wheel base is 14 feet. The pony truck and the leading driver are equalized together, and form, as it were, one truck, having a spread of 9 feet 4 inches. The main and rear drivers are equalized together, and also with the carrying wheels in the trailing truck.

The boiler is of the radial-stayed extension wagon top type. It is 70 inches outside diameter at the front and $77\frac{3}{4}$ inches diameter at the dome course. The heating surface is made up of 198 sq. ft. in the fire-box and 3,678 sq. ft. in the tubes. There are 322 tubes $2\frac{1}{4}$ inches diameter, each being 19 feet 6 inches long. The grate area is 55 square feet, which gives a ratio between grate area and heating surface of 1 to 71.

The rule which takes six times the cubic contents of one cylinder as the means of finding the grate area does not apply to this engine; for in this case the grate area is more than 20 square feet larger than that which would be given by this rule.

The brick arch used in this, as in other types of engines, tends to delay the passage of the hot fire-box gases and to insure their more perfect combustion.

Eight-wheel, or 4-4-0 Type. The Eight-wheel, or American, type, Figs. 32 and 33, was formerly the favorite type for fast passenger service coming within the tractive power possibilities of four-coupled driving wheels. The best type for any service is that which, with the necessary adhesion and boiler capacity, has the smallest numbers of wheels, and is, therefore, the simplest. In this respect the 4-4-0, or Eight-wheel, type is the first choice, and for passenger service, for which the boiler that can be carried on eight wheels is sufficient, this is an ideal type.

The 4-4-0 wheel arrangement provides a four-wheel leading truck with good guiding qualities, and four-coupled driving wheels, affording starting capacity for trains of moderate weight. For passenger service requiring a greater heating surface and grate area than can be provided in the 4-4-0 type, the 4-4-2, or

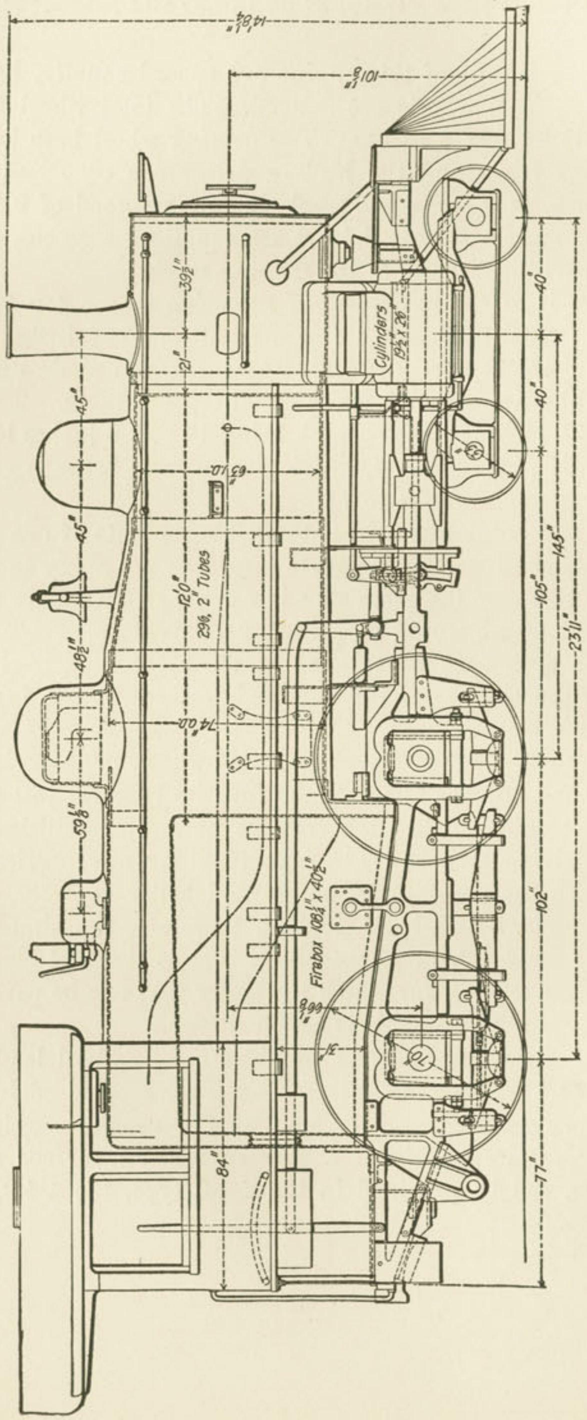


Fig. 32.

SIDE ELEVATION OF EIGHT-WHEEL TYPE PASSENGER LOCOMOTIVE USED ON THE MINNEAPOLIS & ST. LOUIS RAILROAD.

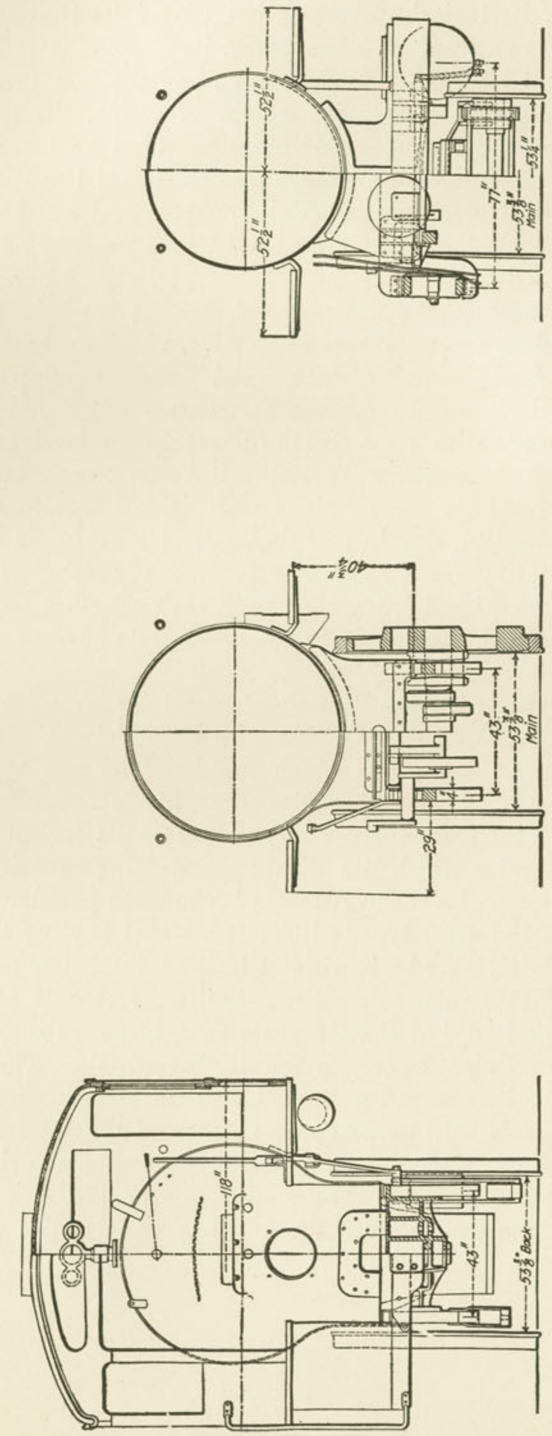


Fig. 33.

SECTIONS AND END ELEVATIONS OF EIGHT-WHEEL TYPE PASSENGER LOCOMOTIVE USED ON THE MINNEAPOLIS & ST. LOUIS RAILROAD.

Atlantic, type is its logical successor; but within its limitations the Eight-wheel is an ideal type because of its simplicity.

Atlantic, or 4-4-2 Type. In deciding upon the best type of locomotive for a given service, the weight of trains, the speed, grades, curvature and frequency of stops must all be carefully considered. In the interest of smooth operation and low cost of repairs, it is desirable to use the minimum practical number of driving wheels within the limits prescribed by the necessary starting power. The Atlantic, or 4-4-2, type, shown in Figs. 34 and 35, owes its development to the necessity of meeting conditions required of the modern fast passenger locomotive, which are summed up in the expressions " sustained high speed " and " regularity of service." By this is meant, not the momentary burst of speed which a small locomotive may occasionally take on level track, nor the high speed of an extra or special of three or four cars when the road is clear, but the more serious and difficult requirements of regular train service, day in and day out, at a 50 or 55 mile schedule, necessitating reserve capacity for severe weather conditions, or for an occasional extra car. For such exacting service much steam is needed, and ample heating and grate surface must be provided.

The 4-4-2 type is the result of the demand for large heating surface and grate area, in combination with large driving wheels, in an effort to meet conditions which could not be met by the American, or 4-4-0, type. When passenger trains outgrew the capacity of the 4-4-0 type, the 4-4-2 type became its logical successor, and for service which lies within the starting capacity of four-coupled driving wheels the Atlantic is the most popular passenger type. In the 4-4-0 type, with a four-wheel leading truck and four-coupled driving wheels without trailers, the boiler capacity is confined within relatively narrow limits. Not only is the heating surface limited, but also the grate area, because the grates must necessarily be placed between the driving wheels. The desirability of large boilers and grates wider than the distance between driving wheels led to a ready acceptance of the 4-4-2 type, which permitted of extending the grates beyond the driving wheels and over the trailing wheels. Because of the favorable arrangement of the grates over the trailing wheels, the 4-4-2

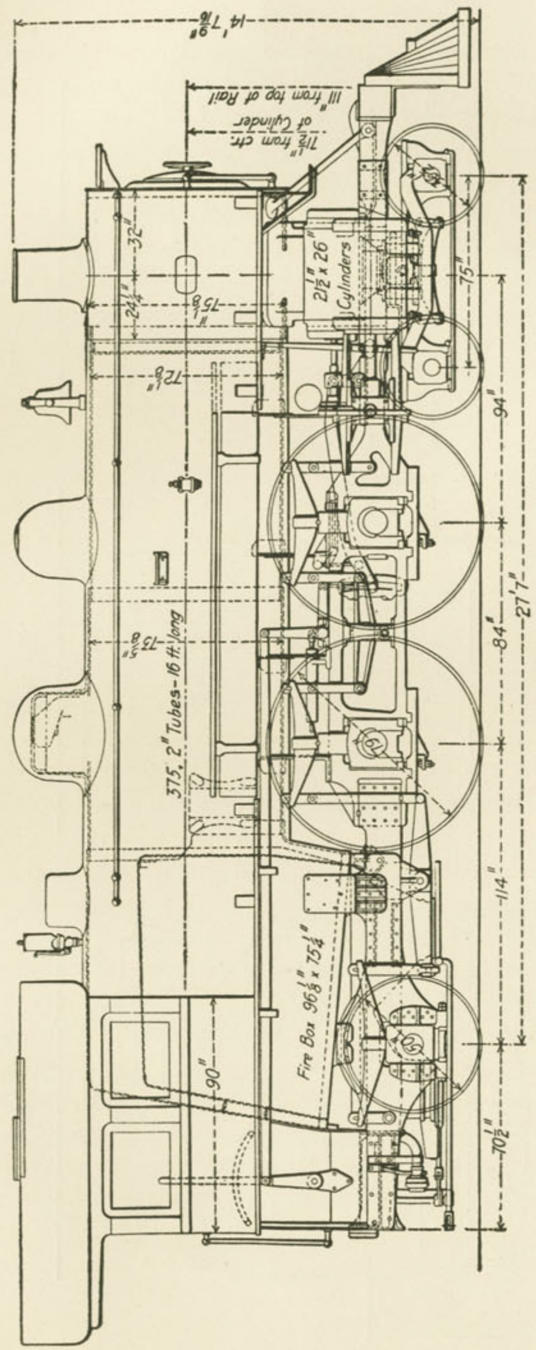


Fig. 34. Side Elevation of Atlantic Type Passenger Locomotive Used on N. Y. C. & H. R. R.

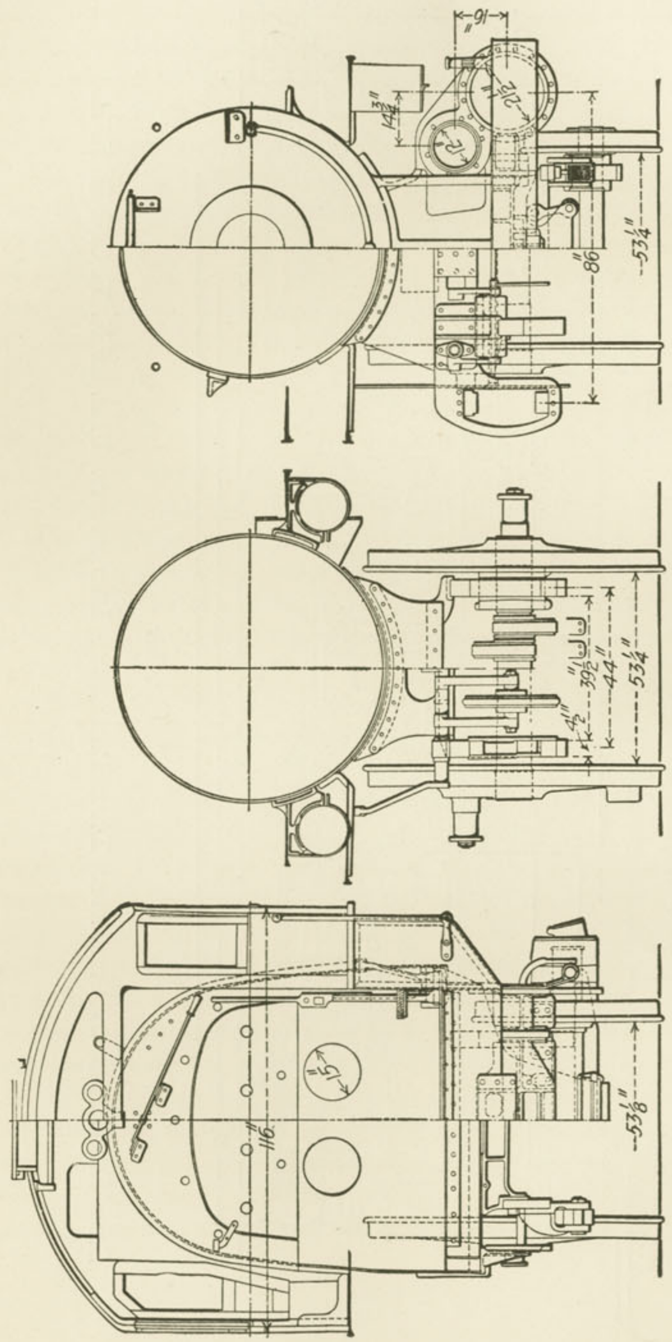


Fig. 35.

SECTIONS AND END ELEVATIONS OF ATLANTIC TYPE PASSENGER LOCOMOTIVE USED ON N. Y. C. & H. R. R.

types have, to a considerable extent, supplanted the 4-4-0 and 4-6-0 types. The 4-4-2 type permits of using a deep as well as wide fire-box, which is especially advantageous for burning bituminous coal, and it provides for wide water spaces, which are favorable to circulation. The advantage gained by the use of trailing wheels in the opportunity for ample depth at the front, or throat, of the fire-box is an important one.

The 4-4-2 type combines a four-wheel leading truck, providing good guiding qualities, and four-coupled driving wheels, having starting capacity for trains of moderate weight, with trailing wheels, which, except on roads with sharp curves, need

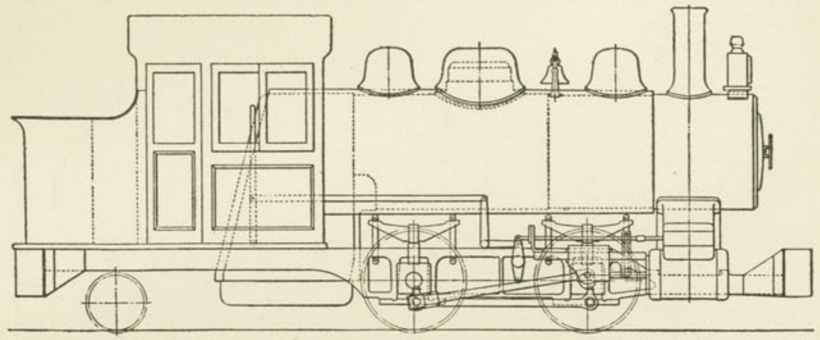


Fig. 36.

FOUR-WHEEL SADDLE TANK LOCOMOTIVE.

not be arranged in a truck having radial motion. This wheel arrangement provides a short, rigid and relatively short total wheelbase. For trains of moderate weight, especially for relatively long runs with infrequent stops, this is the ideal locomotive type. The 4-4-2 type locomotives for the Chicago and Northwestern Railway and the New York Central were the first examples of this design.

Of fifty-eight recent examples of 4-4-2 type passenger locomotives, the proportion of weight on driving wheels to total weight ranges from 50.4 to 60.8 per cent, the average being 55.8 per cent. In studying the proportions of a large number of recent passenger locomotives, several examples of the 4-4-2 type show the least weight in pounds of total weight per square foot of heating surface, and it may be said in general terms that this type offers the opportunity to arrange designs which are exceedingly efficient from this standpoint.

LIGHT LOCOMOTIVES.

A number of different types of locomotives are used for special service where the ordinary road or yard engine is unsuitable. These light locomotives are generally adapted for the use of contractors, mines, logging roads, plantations and industrial plants of all kinds, and for a wide range of service where light rails, poor roadbed and limited clearance are the conditions to be met.

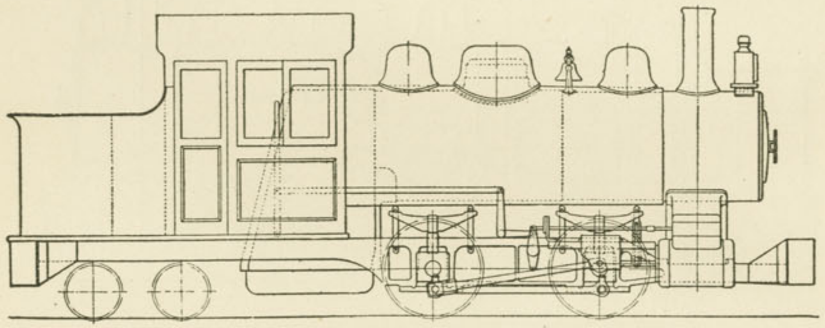
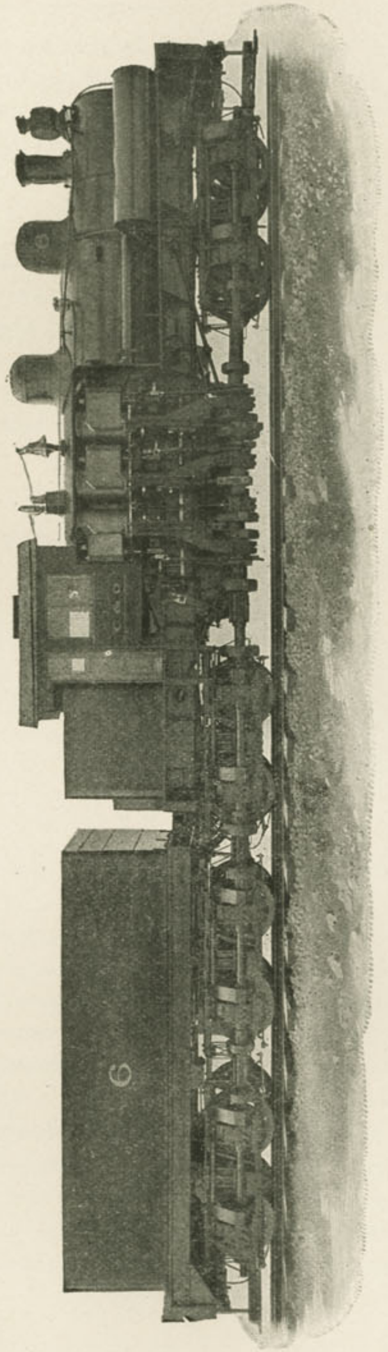


Fig. 37.

Forney, Four-coupled, Tank Locomotive.

The weight, diameter of driving wheels, boiler pressure, tank capacity, smokestack, style of cab, grates and other features of design depend more or less upon special requirements.

For contractors, quarry, mine and industrial service, steel works, blast furnaces, etc., the 0-4-0-T type, shown in Fig. 36, is used extensively. These may have either side tanks or saddle tanks. For somewhat heavier service, the 6-wheel tank, or 0-6-0-T type, is used. For plantation and logging service the four or six-coupled rear truck tank locomotive, Fig. 37, or the four or six-coupled front and rear truck tank locomotives are used. The 0-4-2-T type, shown in Fig. 38, the 2-4-2-T type, the 2-6-2-T type,



CLASS "D" SHAY GEARED LOCOMOTIVE
(The Lima Locomotive and Machine Co.)

and the 2-4-4-T type are also used for suburban service, as is the 0-4-4-T type. The 2-4-0 type, or the four-coupled front truck locomotive, has been very much used for light passenger service, as has also the 4-4-0 type. Light locomotives are also built in the eight-wheel and ten-wheel types for passenger locomotives, and, in the Mogul and Consolidation types, for freight service. The 0-6-0 and the 0-8-0 types for switching service are made in all styles, from a weight of 35,000 pounds to 125,000 pounds.

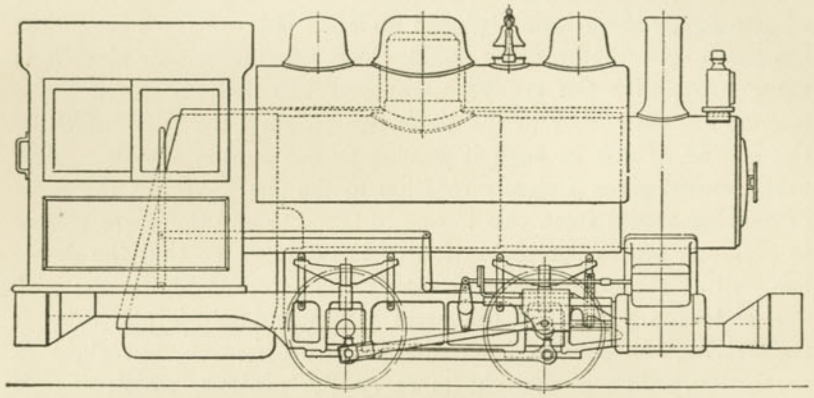


Fig. 38.

FOUR-COUPLED, TRAILING TRUCK, TANK LOCOMOTIVE.

GEARED LOCOMOTIVES.

Geared locomotives are used extensively on logging, mining, plantation, industrial, and on a few standard trunk line railroads. On standard trunk line roads the geared locomotive is not, of course, suitable for through freight service, on account of its relatively limited speed; but in the mountainous sections of such roads, on branch lines, or as a helper engine, it is performing good service on several of the standard railroads.

The geared locomotive is particularly adapted for logging roads, for they, as a rule, combine heavy grades, sharp curves and temporary track. The fact that all the weight is on the drivers fits it for heavy grade work. The freely curving trucks enable it to pass sharp curves with not only small friction, but also without straining or displacing the track, a point which is of considerable importance in temporary roads. On poor tracks, where uneven conditions prevail, a speed of from fifteen to twenty miles per hour may be attained. The advantages, therefore, of a geared locomotive are: It has large tractive power consistent with its weight; is adapted for heavy grade, sharp curves and light rails; and its steady draft, due to the great number of exhausts, makes the combustion of fuel low.

The construction of a geared locomotive generally consists of two or three cylinders placed on each side of the locomotive. On small sizes the crank is double-throw, and on larger sizes it is three-throw with the crank-pins spaced 120 degrees apart. The pistons are connected to the shaft, which runs the full length of the engine, which in turn is geared to the engine wheels. This arrangement gives a steady rotation to the shaft, and as the ratio of gearing varies from two to one to three to one there are twelve to eighteen pulses per revolution of the drivers, so that the draw-bar pull of the engine is very steady. The crank shafts are connected to the pinion by universal joints and slip-joints, so that the driving mechanism is flexible in any direction, but rigid to revolution. The pinion shafts carry the pinions, which engage with the gear rims, which are fastened to the driving wheels. Thrust bars are provided on all pinion shafts to allow for any wear that may take place. The valve motion of geared locomotives is generally of the Stephenson type, which is operated directly from the cab of the locomotive.

Rack Locomotives. For climbing mountains, where the grade is very steep, it is impossible to use the ordinary traction locomotive, so that an arrangement of locomotive, known as a rack locomotive, is used for this purpose. The weight of the locomotive is carried on smooth rails in the ordinary manner, and while the grade lies within the limits of the tractive effort it is propelled by the driving wheels like other engines, but when the grade becomes steep the gear wheel in the center of the locomotive is brought into mesh with a rack rail in the center of the track between the other two. The teeth of the gear on the locomotive engage with those of the rack, and propel the engine independently of the power developed at the driving wheel. The gear axle on the locomotive

is driven through reducing gears by a pair of inside cylinders, so that a rack locomotive has four cylinders, two working on the main axles and two on the gear axles. In addition to the two main axles and the gear axle, there is usually a rear axle which carries a brake pinion.

The four cylinders all have the same diameter and length of stroke, and are independent of each other so far as the steam supply is concerned, and when running along the ordinary track the inner cylinders do not perform any work. Since the adhesion between the wheel and the rail of an engine cannot be taken at more than twenty-five per cent of the weight, when the grade becomes so steep that the wheels will slip the rack locomotive must be used.

REVIEW QUESTIONS.

TYPES OF LOCOMOTIVES.

1. Describe the classification adopted by the American Locomotive Co. for distinguishing the different types of locomotives.

2. What is the name of a locomotive of the 2-8-0 type?

3. What type of locomotive is most generally used for freight service?

4. What proportion of the total weight comes on the drivers of a Consolidation locomotive?

5. Why is it that Consolidation locomotives cannot be designed with large fire-boxes and wide water spaces?

6. Describe four reasons why the Mallet Articulated Compound locomotive has come into extensive use for heavy freight service.

7. What is meant by the articulated feature of the Mallet Compound engine?

8. Give several reasons why the Mallet Compound engine gives greater tractive power than a Consolidation locomotive of the same size.

9. Describe the path which the steam takes in a Mallet locomotive from the steam dome to the exhaust.

10. What arrangements must be made in the steam pipes to allow the Mallet Compound engine to go around curves?

11. To what part of the Mallet Compound engine are the high pressure cylinders attached, and to what part the lower pressure cylinders?

12. On what road are the heaviest types Mallet Compound engines used?

13. Describe briefly the twelve-wheeled type of locomotive, and explain why this type has less weight on the drivers than the Consolidation type.

14. Name five different types of locomotives used in freight service.

15. Describe the ten-wheel type of locomotive, and explain why it is sometimes referred to as the "all around" type.

16. What prominent American railroad does not use any Consolidation locomotives, and what type is used in place of them?

17. Explain the particular class of service in which the Mogul type can be used to advantage.

18. Explain the difference between the Prairie type and the Mogul type of locomotive.

19. Why is it that switching engines do not generally have any front or rear trucks?

20. What type of locomotive is most generally used in heavy passenger service?

21. Describe two types of trailing trucks used with the Pacific type of locomotive.

22. Describe the wheel arrangement of the Prairie type locomotive, and explain several reasons that have caused this type of engine to be used in high speed passenger service.

23. What are the limitations of the eight-wheel type of locomotive?

24. In what way does the Atlantic type of locomotive excel the eight-wheel type for pulling heavy trains at high speed?

25. What is the average proportion of the weight of a locomotive on the drivers of an Atlantic type of locomotive?

26. Describe the uses to which the geared locomotive is particularly adapted.

27. Describe the general construction of a geared locomotive, and explain how it transmits the power from the cylinders to the wheels.

28. Name ten different types of locomotives used for freight service.

29. Explain why Consolidation locomotives are used so extensively in freight service.

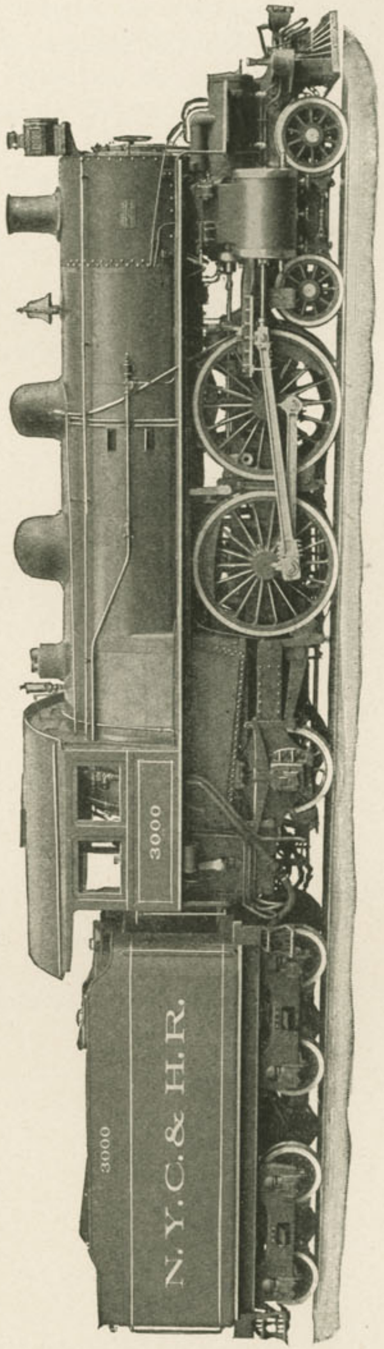
30. What is the average proportion of weight on the drivers of a twelve-wheeled locomotive?

31. What are the particular advantages of the Prairie type when used for freight service?

32. In deciding upon the best type of locomotive for a given service, what factors must be carefully considered?

33. What have been the principal factors which have caused the Atlantic type of locomotive to be so largely used for passenger service.

34. Name the various duties for which light locomotives are best adapted.



COLE FOUR-CYLINDER BALANCED COMPOUND PASSENGER LOCOMOTIVE USED ON THE NEW YORK CENTRAL & HUDSON RIVER RAILROAD

This Locomotive Made the Record on the Testing Plant of the Pennsylvania Railroad at the Louisiana Purchase Exposition at Saint Louis

(American Locomotive Co.)

Compound Locomotives

There are two general types of locomotives in use as regards the steam distribution, namely, the simple engine and the compound engine. While the latter type has been in use for a considerable number of years, a great diversity of opinion still exists regarding its merits. They have given excellent results in some cases, while in others the cost of repairs has more than offset their economy, so that their use, especially in the older types, has been discontinued.

Object of Compounding Locomotives. The principal object in compounding locomotives is to effect economy in fuel, which economy is obtained by the consumption of a smaller quantity of steam in the cylinders, and hence the evaporation of less water. The expansion of the steam is divided between two cylinders, so that higher steam pressures may be used, greater expansion obtained anl less cylinder condensation result.

Decline of the Compound Engine. While there is no question that the compound engine embraces the correct principle of steam distribution, yet in recent years the number of new compound locomotives built has been continually declining. Were it not for the new types of compound locomotives which have been recently built, it is fair to assume that the compound engine, as formerly built, would not be used at all. The decline of the compound can be shown from the following figures: Only 157 locomotives of the compound type were ordered in 1907, and these were ordered by five railroads. This compares with 240 engines in 1906, 160 in 1905, and 211 engines in 1904. In 1906 the number of compound engines slightly exceeded four per cent of the total number, while in 1907 the number was less than four per cent.

Types of Compound Engines Being Built. In regard to the types of compound engines ordered in 1907, 36 of them were of the four-cylinder balanced type, 20 were of the two-cylinder type, and 81 were the Mallet four-cylinder type. Of the four-cylinder type all were used on the Santa Fe except three which were used on the St. Paul, the latter using them with Pacific type of wheel arrangement. Of the Mallet Compound, the Northern Pacific ordered 16 Mallet four-cylinder compounds with pony trucks front and back, and six drivers coupled in each unit. The other 65 Mallet engines were built for the Great Northern; but they have no engine trucks, each element having eight drivers coupled.

THE VAUCLAIN FOUR-CYLINDER COMPOUND.

Among the earliest engineers to recognize that valuable economies of fuel and water can be effected by the use of compound

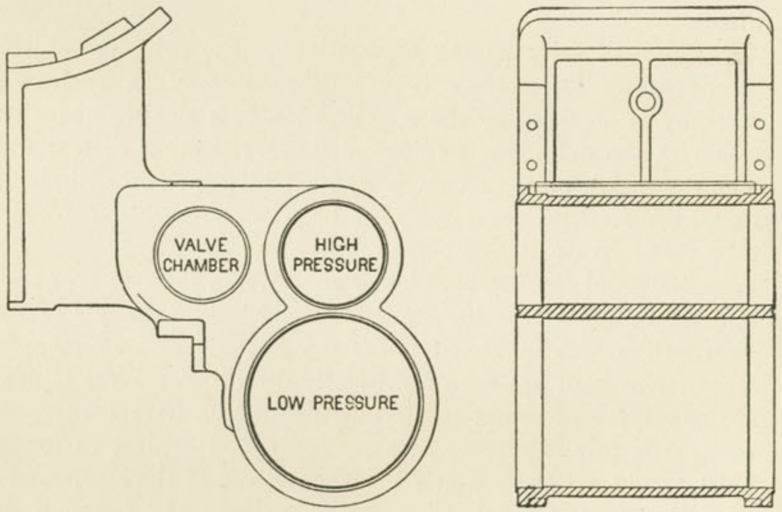


Fig. 1.

General Arrangement of Cylinders on a Vauclain Compound.

instead of single-expansion engines was Samuel M. Vauclain, of the Baldwin Locomotive Works, who in 1889 designed and had constructed the original form of compound engine known as the

Vauclain four-cylinder compound. Nearly 3000 locomotives of this type have been built for use in the United States, but a large number of these have been changed to simple engines, owing to the difficulty in keeping them in repair and in good working order. As representing one of the types of compound engines which have been most widely used, they are very interesting.

Arrangement of Cylinders. The cylinders consist of one high-pressure and one low-pressure for each side, the ratio of volumes being about three to one. They are cast in one piece with the

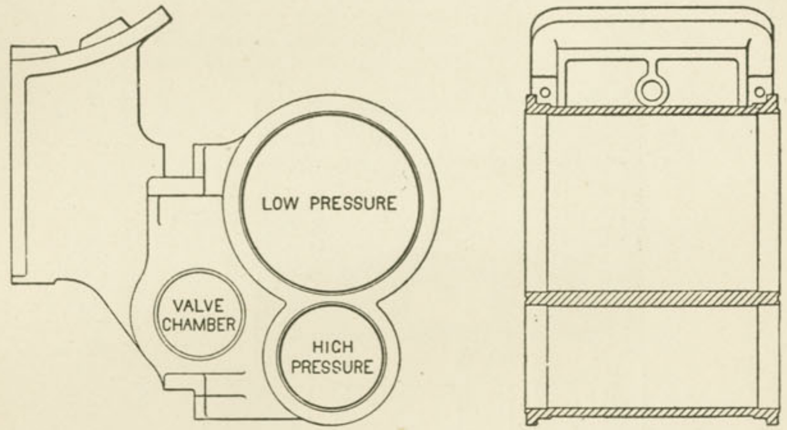


Fig. 2.

Special Arrangement of Cylinders on a Vauclain Compound.

valve chamber and saddle, the cylinders being in the same vertical plane and as close together as they can be, with adequate walls between them. The high-pressure cylinder is generally put on top on the eight-wheel or American type passenger locomotives, as shown in Fig. 1, while the arrangement shown in Fig. 2 is used in Mogul, Consolidation and Decapod locomotives. On each side the high and low-pressure piston takes hold of a single crosshead. The steam distribution is controlled by a single balanced piston valve, so that the valve gear is the same as the single-expansion engine, except that four cylinders are used instead of two. The distribution of steam in the Vauclain compound is shown by the diagram, Fig. 3. The arrangement of the cylinders in relation to the valve is, for convenience of reference, somewhat distorted. The valve employed is of the piston type, working in a cylindrical

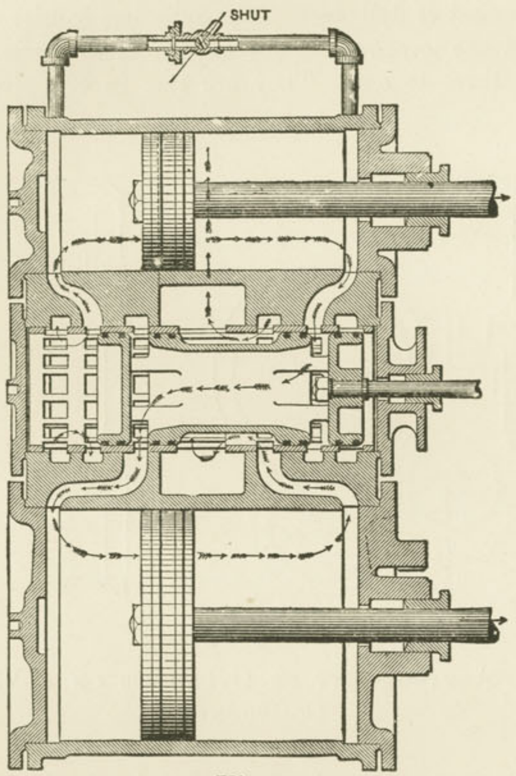


Fig. 3.

DIAGRAM OF STEAM DISTRIBUTION IN VAUCLAIN FOUR-CYLINDER COMPOUND.

chest located in the saddle casting between the cylinders and the smoke-box, and as close to the cylinders as convenience will permit. It is surrounded by an independent bushing, with port openings machined to exact dimensions, so that the admission of

steam will be uniform under all conditions, as shown in Fig. 4. By the use of this bushing repairs can be made from time to time, and changes effected in the port openings, without the necessity of altering the cylinder castings. The bushing is forced into the cylinder casting by hydraulic pressure.

Function of the Valve. The function of the valve is to control the admission and exhaust of both cylinders. Live steam enters the chest at both ends of the valve, and is admitted to one end of the high-pressure cylinder. The exhaust from the high-pres-

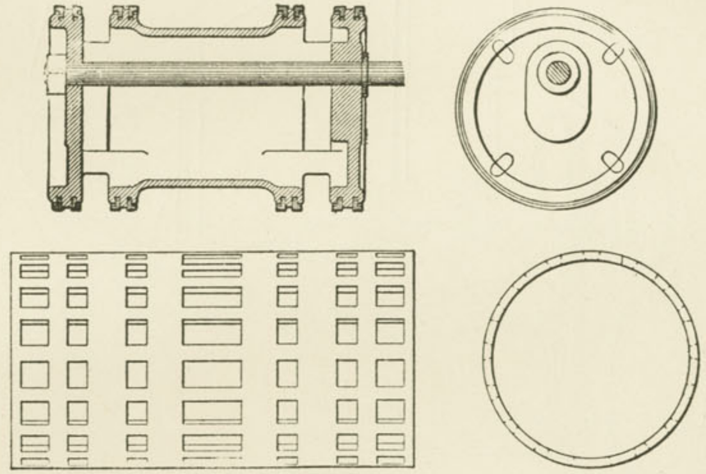


Fig. 4.

VALVE AND BUSHING USED ON VAUCLAIN COMPOUND ENGINE.

sure cylinder passes through the central hollow portion of the valve and supplies the low-pressure cylinder, while at the same time the steam in the opposite end of the low-pressure cylinder is allowed to escape under the valve to the final exhaust in the stack.

By-pass Valve. In order to obtain the maximum starting power in any compound locomotive it is necessary to employ some means of admitting live steam to the low-pressure cylinder. The device for this purpose in the Vauclain four-cylinder type is a by-pass valve, which is opened to allow the steam to pass from one end of the high-pressure cylinder to the other, and from thence to the low-pressure cylinder. This arrangement is shown in Fig. 5, in which 1 represents the starting lever in the cab; 2, the starting lever fulcrum; 3, the starting valve rod from the cab; 4, upper arm; 5, lower arm; 6, shaft; 7, starting valve rod under cylinder;

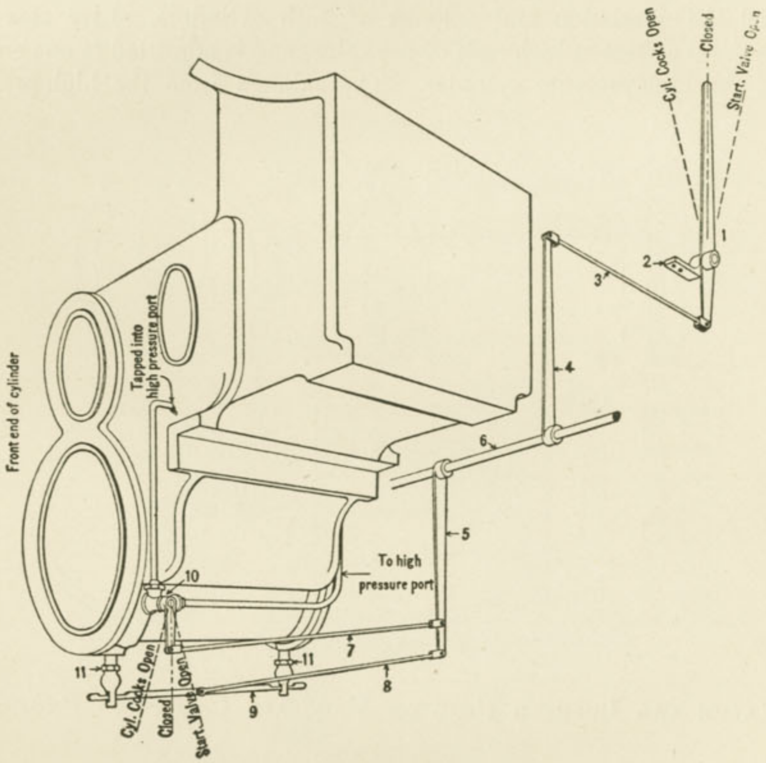


Fig. 5.

Arrangement for Starting Vauclain Compound Locomotives.

8, cylinder cockrod; 9, cylinder cock strip; 10, starting valve; 11, cylinder cock.

When the valve is put into position for starting, live steam passes from that end of the high-pressure cylinder, in which the

main valve is admitting steam, through the starting valve to the other end of the high-pressure cylinder, and then through the exhaust to the low-pressure cylinder. This allows the full power of the boiler to be exerted on the low-pressure cylinder, while the high-pressure piston is nearly balanced by the steam on both sides. As the engine gets up to speed, the steam that enters the low-pressure cylinder through the starting valve decreases as the speed increases. This valve should be kept shut during the normal operation of the engine.

Air Valves. As is usual in all engines, air valves are placed

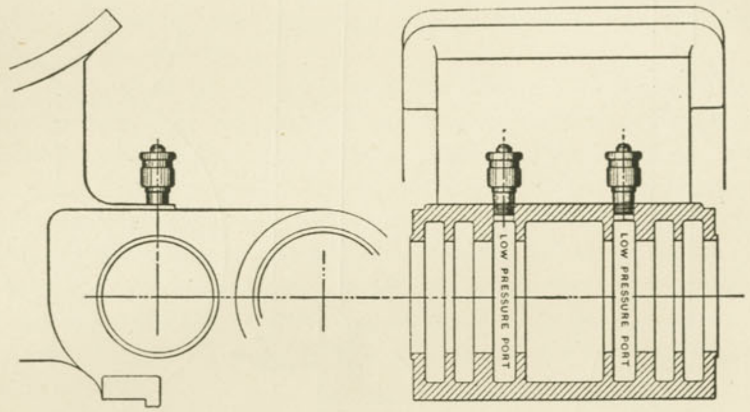


Fig. 6.

Vacuum Valves for Low Pressure Cylinder Ports of Vauclain Compound Locomotives.

in the main steam passage of the high-pressure cylinder; but in the Vauclain compound, additional air valves, as shown in Fig. 6, are placed in the steam passages of the low-pressure cylinders to supply them with sufficient air to prevent the formation of a vacuum. Water relief valves, as shown in Fig. 7, are applied to the low-pressure cylinder to prevent the rupture of the cylinder in case there is excessive pressure in the cylinders.

Operation of the Vauclain Compound. In starting the locomotive with a train, place the reverse lever in full forward position, throw the cylinder cock lever in full forward position, which operation opens the starting valve and admits live steam into the low-pressure cylinder. The throttle valve is then opened, and as soon as possible, when the cylinders are free of water and the train is under good headway, the cylinder cocks and starting valve should be closed. After the starting valve is closed, and as the speed of the train increases, the reverse lever should be hooked back a few notches at a time until the full power of the locomotive is developed. If, after moving the reverse lever to the last notch, which cuts off steam at about half stroke in the

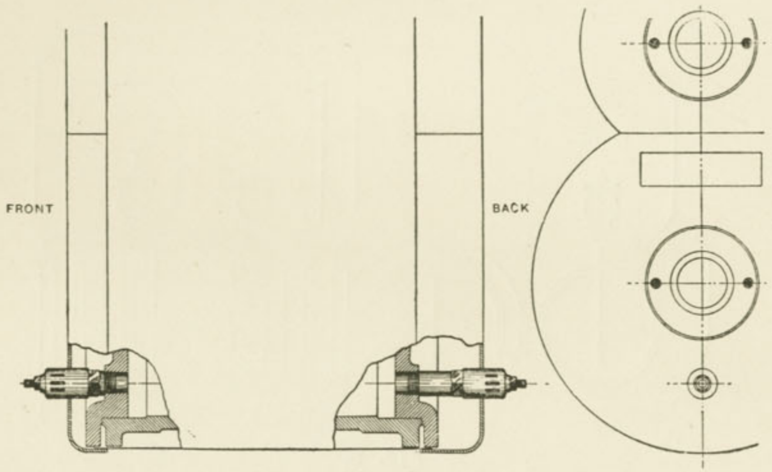


Fig. 7.

Relief Valves for Low Pressure Cylinder Heads of Vauclain Compound Engines.

high-pressure cylinder, it is found that the locomotive develops more power than is required, the throttle should be partly closed and the amount of steam flowing to the cylinder reduced. On small descending grades the steam may be throttled very close, allowing just enough steam in the cylinders to keep the air-valves closed. If the descending grade is large, preventing the use of steam, close the throttle and move the reverse lever gradually to full notch, and move the starting lever to its ful backward position. This allows the air to circulate either way through the

starting valve from one side of the piston to the other. It relieves the vacuum and prevents the oil from being blown out of the cylinder. On ascending grades with heavy trains, as the speed decreases, the reverse lever should be moved forward sufficiently to keep up the required speed. If, after the reverse lever is placed in the full forward notch, the speed still decreases and it is absolutely necessary, the starting valve may be used, admitting steam into the low-pressure cylinders. This, however, should be done only in cases of emergency and the starting valve closed as soon as possible.

Precautions When Running Vauclain Compound Engines. Among the precautions necessary when running a Vauclain compound are the following:

The reverse lever should never be hooked up until after the cylinder cock lever is in central position; the starting device should never be used for any other purpose than starting the train; placing the cylinder cock lever in central position causes the engine to work compound; running with starting valve open and with throttle partly closed, the reverse lever being hooked up in top notch, is wasteful; the by-pass valve, admitting live steam to low-pressure cylinder, should not be opened until the lever is in last notch; on account of the mild exhaust, the fireman should carry as light a fire as possible.

TWO-CYLINDER COMPOUND OR CROSS-COMPOUND LOCOMOTIVES.

The cross-compound locomotive shown in Fig. 8 has two cylinders, one on each side, arranged with an intercepting valve so that the engineer can work the engine either simple or compound. When the engine is worked as a simple engine, the pressure of the steam that is admitted to the low-pressure cylinder is controlled by an automatic reducing valve in such a manner that it shall bear the same ratio to the pressure of steam admitted to the high-pressure cylinder as the volume of high-pressure cylinder bears to the volume of the low-pressure cylinder.

The essential features of the Baldwin design of this engine, brought out first in 1898, are the intercepting and reducing mechanism. These, when in normal position, permit the locomotive to operate by single-expansion, and to so continue until changed to compound. The locomotive is therefore readily started at any position of the crank.

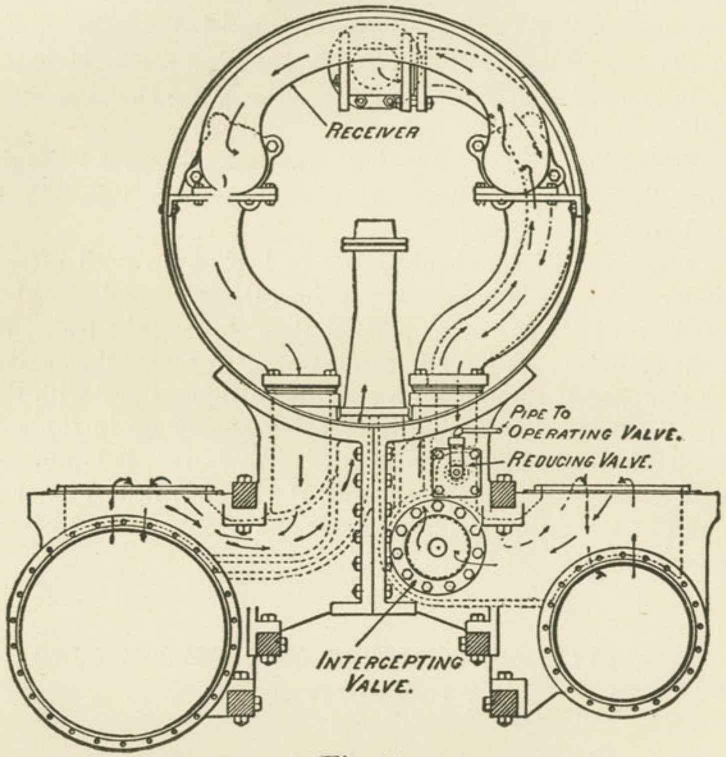


Fig. 8.

Cross Section of Two-cylinder Compound.

Intercepting Valve. In the diagrams, Figs. 9 and 10, A is a double piston intercepting valve, located in the saddle casting of the high-pressure cylinder. In one direction the movement is controlled by a spiral spring, in the other by steam pressure. The function of the intercepting valve is to cause the exhaust steam from the high-pressure cylinder to be diverted, at the option of the

engineer, either to the open air when working single-expansion, or to the receiver when working compound. C is a reducing valve, also placed in the saddle casting of the high-pressure cylinder, and, like the intercepting valve, is moved in one direction by a spiral spring, and in the opposite direction by steam pressure. The function of this valve is, in its normal position, to admit live steam into the receiver at reduced pressure while the locomotive is working single expansion. When the locomotive is working compound this valve automatically closes, as it is evident that there is no further need of live steam in the receiver. A further function of

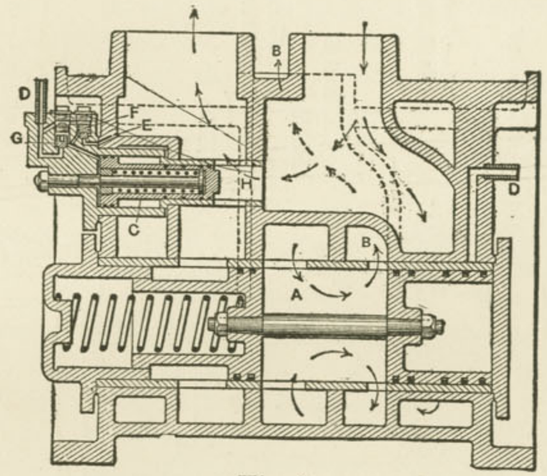


Fig 9.

Two-cylinder Compound. Position of Valves when Working Single Expansion.

the reducing valve is to regulate the pressure in the receiver, so that the total pressure on the pistons of the high- and low-pressure cylinders may be equalized. The steam for controlling the operation of both intercepting and reducing valves is supplied through the pipes D from the operating valve in the cab.

Operating and Reducing Valves. When not permanently closed by pressure in the pipes D, the reducing valve C is operated automatically by the pressure in the receiver. To this end the port E is provided, communicating with the receiver and the space in front of the reducing valve; as the pressure rises, the steam acts on the large end of the reducing valve, causing it to move backward and close the passage H through which steam enters the receiver, and thus prevent an excess pressure of steam in the low-pressure cylinder. Poppet valves F and G are placed in connection with the port E, one to prevent the escape of steam from the

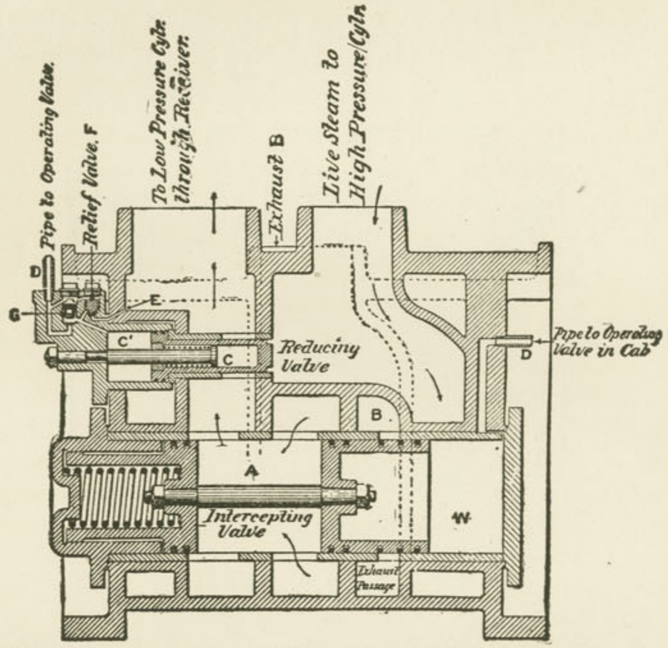


Fig. 10.

Two-cylinder Compound. Position of Intercepting and Reducing Valves When Working Compound.

receiver to the pipe D when the locomotive is working single expansion, and the other to close the passage from pipe D to the receiver when working compound.

Normally the lever of the operating valve in the cab is in the position marked "simple." In this position no steam is allowed to enter the pipes D, and no pressure will be exerted on the inter-

cepting and reducing valves in opposition to the springs, and they will assume the positions shown in Fig. 9. The ports of the intercepting valve A stand open to receive the exhaust steam from the high-pressure cylinder and deliver it through the exhaust passage B to the atmosphere. The reducing valve is open, admitting live steam through passage H to the receiver, and from thence to the low-pressure cylinder. The receiver pressure is governed by the automatic action of the reducing valve as previously explained. In this way the locomotive can be used single expansion in making up and starting trains for switching and slow running.

At the will of the engineer the operating valve in the cab is moved to the position marked "Compound." This admits steam to the pipes D and through them to the valve chambers W and C, changing the intercepting and reducing valves instantly and noiselessly to the positions shown in Fig. 10. The exhaust from the high-pressure cylinder is diverted to the receiver, the admission of live steam to the receiver is stopped by the closing of the passage H, and the locomotive is in position to work compound. Both valves are of the piston type, with packing rings to prevent leakage.

Schenectady Cross-Compound Engine. Another type of cross-compound engine in use is the Schenectady compound engine, invented by A. J. Pitkin, of the American Locomotive Works, at Schenectady, N. Y. The arrangement of the cylinders and the intercepting valve is practically the same as in a Baldwin compound, the principle difference being in the construction and operation of the intercepting valve.

With the arrangement of valves shown in Figs. 11 and 12, the engine can be started and run either compound or simple, and can be changed from compound to simple or from simple to compound at the will of the engineer, with any position of throttle and at any point of cut-off. The part which each valve does in accomplishing this is as follows:

The separate exhaust valve when open allows the steam to exhaust direct from the high-pressure cylinder to the atmosphere without going through the low-pressure cylinder, thus working the engine simple, and when closed causes the steam from the high-pressure cylinder to go through to the low-pressure cylinder, thus working the engine compound. The intercepting valve closes the passage between the cylinders when the separate exhaust valve is open, so that steam cannot go from the high-pressure cylinder to the low-pressure cylinder, and it also admits steam to the low-pressure cylinder direct from the dry pipe through the reducing valve. When the separate exhaust valve closes, the intercepting valve opens the passage between the cylinders and cuts off the supply of steam from the dry pipe to the low-pressure cylinder.

The reducing valve works only when the engine is running simple and throttles the steam passing through it, so that the

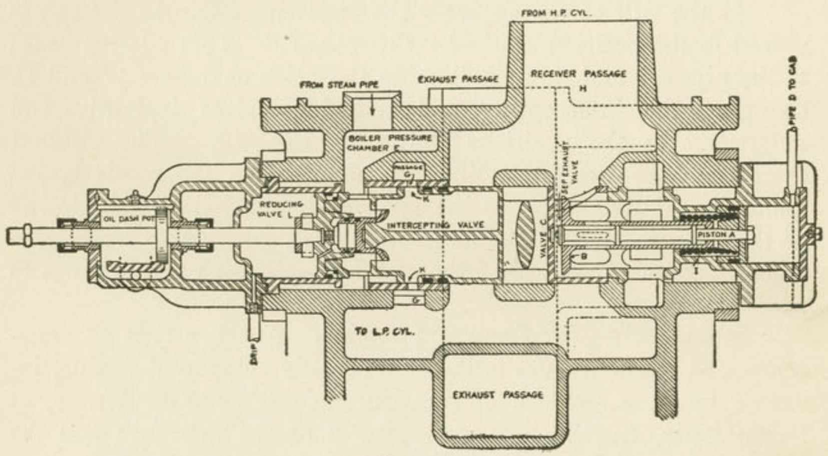


Fig. 11.

Position of Intercepting Valve on a Schenectady Compound Engine when Running Simple.

pressure of steam going to the low-pressure cylinder is about one-half the steam pressure in the dry pipe.

Operation of Intercepting and Reducing Valves. The intercepting and reducing valves are worked automatically by the steam pressures acting on the difference of areas of the ends of the valves, and their movement is cushioned by dash-pots. The separate exhaust valve is operated by the engineer by means of a three-way cock in the cab. To open the separate exhaust valve, the handle of the three-way cock is thrown so as to admit air or

steam pressure against the piston "A." Pulling the handle back relieves the pressure against "A," and the spring which is shown in the figures shuts the valve.

All the engineer has to do in connection with the operation of the valves is to pull the handle of a three-way cock in the cab one way or the other, according as the engine is to run simple or compound. The engineer uses this handle under the following conditions:

Starting a Schenectady Compound Engine. First, to start simple. Under ordinary conditions it is not necessary to start the engine simple; but if the maximum tractive power of the engine is needed to start a heavy train, the engineer pulls the handle of the three-way cock, so as to admit pressure on the piston A, which is then in the position shown in Fig. 11. This will force the piston A into the position shown in Fig. 12, which opens the separate exhaust valve and holds it open. As soon as the throttle is opened, steam at boiler pressure enters the chamber E and forces the intercepting valve against the seat B, as shown in Fig. 12. Steam enters the high-pressure cylinder and is exhausted through the reservoir through the receiver pipe and separate exhaust valve to the atmosphere, as shown in Fig. 12. Steam also enters the low-pressure cylinder from the chamber E through the reducing valve L and ports G, and is exhausted in the usual way. The steam is prevented from reaching the low-pressure cylinder at boiler pressure by going through the reducing valve. As will be seen from Fig. 12, the valve is partly balanced by the cylinder open to the atmosphere, and boiler pressure acting on the unbalanced area throws the valve to the right. When the pressure on the right of the valve becomes high enough it will throw the valve to the left, because it acts on the whole area of the valve, and in so doing throttles the steam to the proper pressure for the low-pressure cylinder.

Position of Valves When Running Compound. Having started the train in this way, when the engineer wishes to change the engine from running simple to running compound he pushes the handle of the three-way cock to its first position, which relieves the pressure on the right of the piston A, and the spring throws that piston to the right into the position shown in Fig. 11, closing the separate exhaust valve. As soon as this valve is closed, the pressure in the receiver rises and presses the intercepting valve to the left against the pressure in the chamber E, which only acts as an unbalanced area of the valve. The receiver pressure holds the intercepting valve to the left, as shown in Fig. 11, closing the ports G and opening free passage from the high-pressure cylinder to the low-pressure cylinder, and the engine works compound.

It will be noticed that while working compound, which is the usual way of working the engine, the intercepting and reducing valves are both held against ground joint seats, which prevent the leakage of steam that may have leaked past the packing rings.

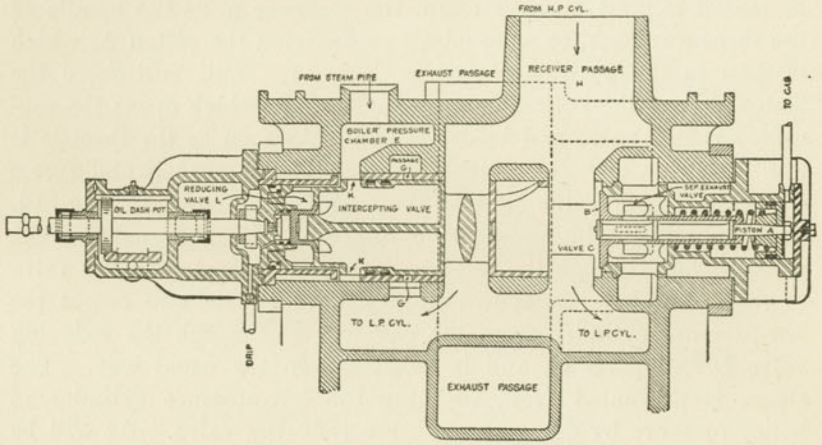


Fig. 12.

Position of Intercepting Valve on a Schenectady Compound Engine when Running Compound.

Changing from Compound to Simple. Now, with the engine running compound, if the engineer wishes to run the engine simple, because of a heavy grade, the handle of the three-way cock is pulled the same as for starting simple. This will open first the by-pass valve C, and then the separate exhaust valve, the by-pass valve relieving the pressure more gradually than if the large valve were opened at once. As soon as the separate exhaust valve is open, the pressure in the receiver drops, and the intercepting valve is forced against the seat B by the pressure in the chamber

E, and the engine runs simple as before. When the grade is passed, the engineer pushes the handle of the three-way cock over, and the engine begins to work compound.

Starting the Engine Compound. To start the engine compound the separate exhaust valve is left closed, as in Fig. 11, and when the throttle is opened the intercepting valve will be forced against the seat B by the pressure in the chamber E, as shown in Fig. 12. The low-pressure cylinder will then take steam through the ports G, and the high-pressure cylinder will exhaust into the

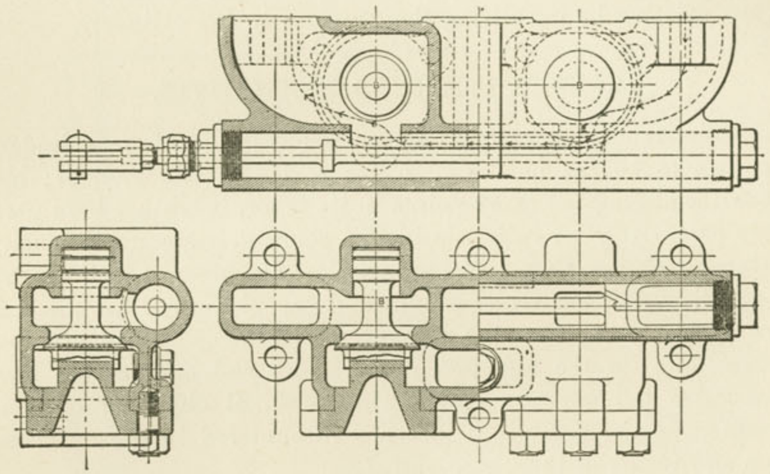


Fig. 13.

Position of By-pass Valves on a Schenectady Compound when Drifting.

receiver for a few strokes of the engine. This will raise the pressure in the receiver and force the intercepting valve into the position shown in Fig. 11, closing the ports G, and the engine will run compound. The combination of the automatic intercepting valve with the separate exhaust permits the engine to be changed from simple compound, and the reverse, without jarring or jerking the train.

Position of Valves When Drifting. When drifting, or not working steam, the by-pass valves B, B, shown in Fig. 13, being in a vertical position, fall away from their seats by gravity, and give a clear opening between the two ends of the high-pressure cylinder. The by-pass valves for the low-pressure cylinder are also in a vertical position, and are held to their seats by the steam pressure when working steam. When running with closed throttle, the by-pass valves are raised from their seats by any pressure on the lower side, assisted by the spring under the valve. With the valves raised from their seats, there is a continuous opening between the two ends of the low-pressure cylinder through the cylinder steam ports into the steam chest, providing relief from back pressure when drifting by equalizing the pressure in the cylinders.

TANDEM COMPOUND LOCOMOTIVES.

The tandem compound locomotive with its four cylinders appears to be the ideal design for compound locomotives; but notwithstanding the many points in its favor, it has not been used very extensively on railroads in this country. Among the many points in its favor are that the cylinders are brought in line; one connecting rod, one set of guides and one piston rod are all that are needed to operate the drivers; and although there are two valves, one for the high-pressure cylinder and one for the low, one valve rod operates both. The principal objection to it is based upon the difficulties that are encountered in the examination and repair of the piston valves.

American Tandem Compound Locomotive. The tandem compound locomotives which have been built are used principally for heavy freight service. The general arrangement of cylinders, pistons and valves constructed by the American Locomotive Co. is shown in Fig. 14. The high-pressure cylinder is forward of the low-pressure cylinder, with both pistons on the same rod. The steam chest is common to both high and low-pressure cylinder, being open from end to end and serving the purpose of a receiver. The valves are hollow, and permit an unrestricted flow of steam through the steam chest. On the high-pressure cylinders the valves are arranged for internal admission, and on the low-pressure cylinders for external admission. This design of valve allows steam to be admitted to the same side of each piston by means of the crossed ports on the high-pressure cylinder.

To work the engine, simple or compound, a starting valve is used. When live steam is admitted directly into the low-pressure cylinders, the starting valve uncovers ports in the steam chest, which admits high-pressure steam into the low-pressure cylinder. When working compound, the starting valve is moved back over the ports, shutting off steam in its passage to the low-pressure end of the steam chest.

Baldwin Tandem Compound. In the Baldwin type of tandem

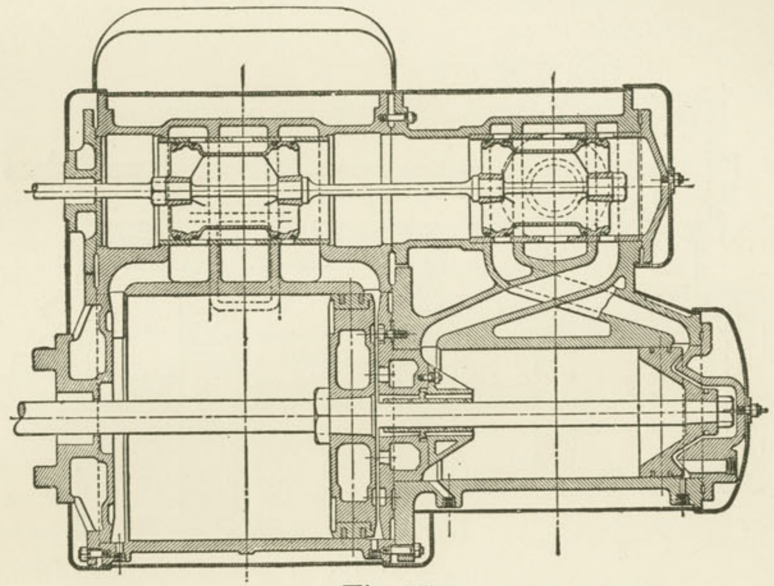


Fig. 14.

General Arrangement of Cylinders, Pistons and Valves, American Tandem Compound Locomotive.

compound, Fig. 15, which was designed in 1902 principally for heavy freight service, four cylinders are used with a high and low-pressure cylinder and cylindrical valve chest on each side. The high-pressure cylinder is placed in front of the low-pressure, both having the same axis; that is, the center of the low-pressure cylinder extended becomes also the center of the high-pressure.

Each cylinder with its valve chest is cast separately, and is separate from the saddle. The steam connections are made by a pipe from the saddle to the high-pressure valve chest, and the final exhaust takes place through an adjustable connection between the low-pressure cylinder and the saddle casting. The valve, which is double and hollow, admits steam to the high-pressure cylinder, and at the same time distributes the high-pressure exhaust from the front end of the high-pressure cylinder to the back end of the low-pressure cylinder, or *vice versa*, as the case may be, without the necessity of crossed ports. As shown in Fig. 15, A is the high-

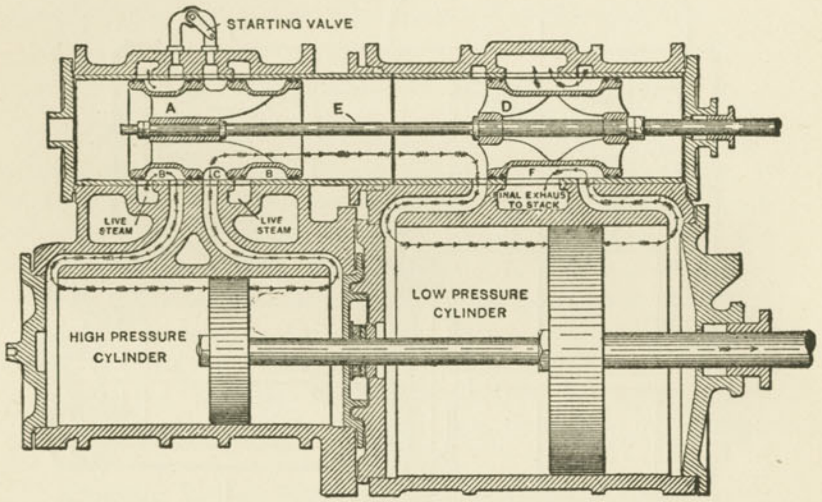


Fig. 15.

STEAM DISTRIBUTION IN TANDEM COMPOUND CYLINDERS.

pressure valve by which steam is conducted from the live-steam openings through external cavities B and B to the high-pressure cylinder. The exhaust from the high-pressure cylinder passes through the opening C to the steam chest, which acts as a receiver; D is the low-pressure valve connected to the high-pressure valve by valve rod E. This valve in its operation is similar to the ordinary slide valve. The outside edges control the admission, and the exhaust takes place through the external cavity F. The starting valve connects the live steam ports of the high-pressure cylinder.

THE BALANCED COMPOUND LOCOMOTIVE.

In all two-cylinder locomotives, whether single-expansion or compound, and in four-cylinder types such as the tandem and the original Vauclain compound, the reciprocating parts are counterbalanced by rotating weights in the driving-wheels.

This arrangement of balance becomes unsatisfactory, particularly for heavy locomotives, and when extremely high speeds are attained. By balancing the reciprocating parts against each other the rotating balance in the wheels used to complement these parts can be eliminated, avoiding to a great extent the vertical shocks and reducing the strain upon the track to that directly due to the weight of the locomotive. Consequently, with a self-balanced arrangement of reciprocating parts, the weight on the driving-wheels may be increased without damaging the track, and higher speed is attainable without undue strain upon the working parts of the locomotive.

With the increasing weight of trains and severity of service, it has been found to be impracticable to keep on increasing the weight and size of locomotives beyond certain limits which these conditions demand. Therefore, to increase the capacity, improve the economy and at the same time reduce the injury to the track, a new type of locomotive has been developed. This is known as the balanced compound engine, which type of engine has been developed quite extensively in Europe. Four cylinders are used, connected on quarters.

Advantages of Four-cylinder Balanced Compounds. The advantages of the four-cylinder balanced compound locomotive are:

1. The approximately perfect balance of the reciprocating parts combined with the perfect balance of the revolving weights results in a locomotive perfectly balanced in all respects.

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

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

4. There is greater economy of fuel and water.

5. The subdivision of power between four cylinders and two axles reduces the bending strain on the crank axle due to the piston

thrust. Because of this division of power, lighter moving parts may be used, which renders them easily handled, and which will minimize wear and repairs.

6. The design may be simple, as one set of valve gears with comparatively few parts may be used.

The balancing of high-speed locomotives by the use of four cylinders connected on the quarters has proven to be a good thing for the locomotive and the track. Its increased complication, however, has made it somewhat unpopular from the roundhouse and shop standpoint. Up to a comparatively recent time the balanced principle has always been employed in connection with compounding. The economy to be obtained from compounding was what was chiefly desired, the advantages of balancing being largely incidental.

Balanced Simple Engines. A few engines have been built and are being experimented with which use four simple cylinders connected on the balanced principle; but no advantage in economy can be obtained with this type unless superheated steam is used.

THE BALDWIN BALANCED COMPOUND.

The balanced compound, built by the Baldwin Locomotive Works since 1902, is designed to obtain all the advantages of balancing and compounding features, and at the same time simplify, as far as possible, the arrangement of the working parts. The cylinders are a development of the original Vauclain four-cylinder compound type, with one piston slide valve common to each pair. Instead of being superimposed and located outside of the locomotive frames, the cylinders are placed horizontally in line with each other, the low-pressure outside and the high-pressure inside the frames. The slide valves are of the piston type, placed above and between the two cylinders which they are arranged to control, as shown in Fig. 16. A separate set of guides and connections is required for each cylinder.

Position of Cylinders. The two high-pressure cylinders being placed inside the frames, the pistons are necessarily coupled to a crank axle. The low-pressure pistons are coupled to crank-pins on the outside of the driving-wheels. The cranks on the axle are

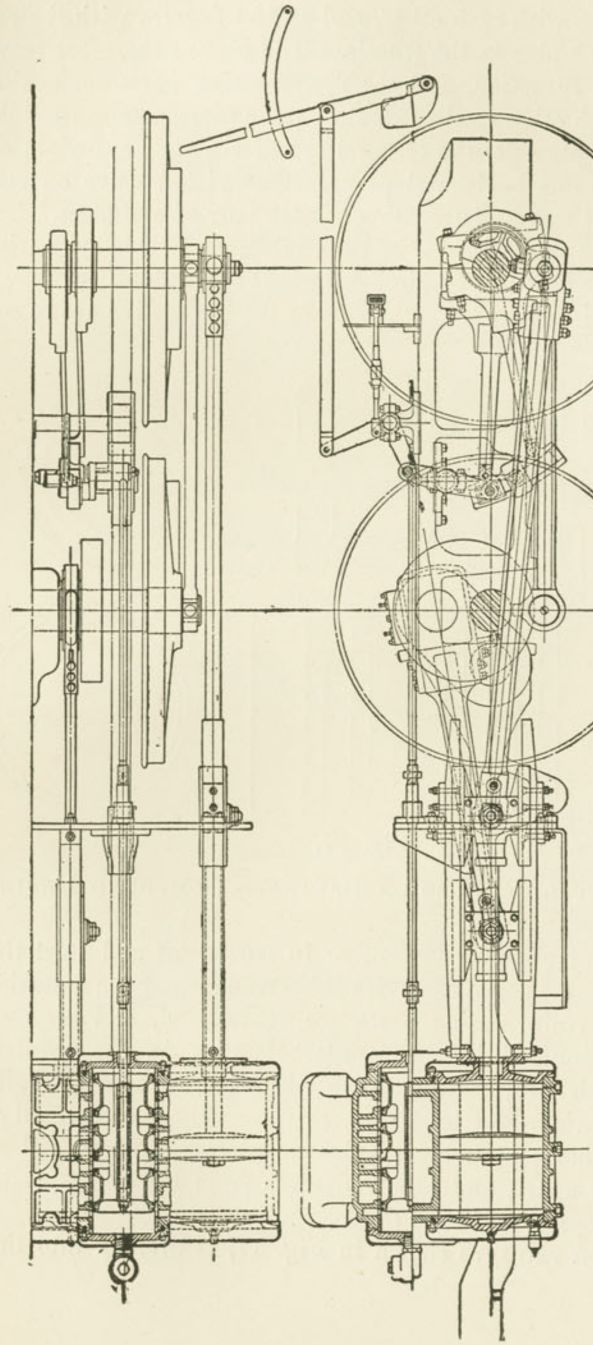


Fig. 16. Driving Gear and Valve Motion Baldwin Balanced Compound Locomotive. (Baldwin Locomotive Works.)

set at 90 degrees with each other, and at 180 degrees with the corresponding crank-pins in the wheels. The pistons therefore travel in the opposite direction, and the reciprocating parts act against and balance each other to the extent of their corresponding weight.

Whenever possible, the center lines of the four cylinders are placed in the same horizontal plane. One piston valve on each side controls the steam distribution to each pair of cylinders. The two cylinders on the same side of the engine, with their cylindrical steam chest, are cast in one piece with half the saddle.

The two pistons on the same side of the locomotive are so con-

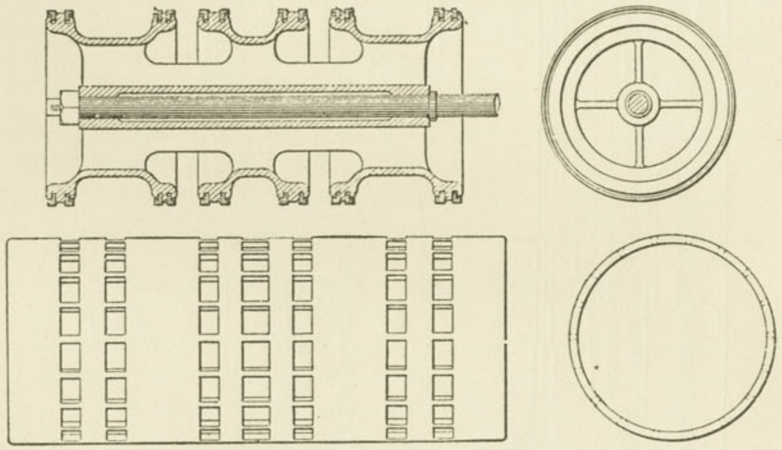


Fig. 17.

VALVE AND BUSHING USED ON BALANCED COMPOUND ENGINES.

nected that they oppose one another in movement and start their strokes at the same instant. With this arrangement the disturbing effects of the reciprocating parts are neutralized, and no excess weights are required in the counterbalance. As the revolving weights are balanced, the maximum wheel pressure on the rail is that of the static wheel load. If, as is usually the case, all the cylinders are horizontal, the cranks are placed one hundred and eighty degrees apart, and ninety degrees from the corresponding cranks on the opposite side of the locomotive.

The piston valve, as shown in Fig. 17, is divided into three

sections, and is arranged to admit the exhaust steam from either end of the high-pressure cylinder into the corresponding end of the low-pressure cylinder. The valve operates in a hard cast-iron bushing, shown in Fig. 17, which is forced into the steam chest by hydraulic pressure. The valve is arranged for central admission with reference to the high-pressure cylinder.

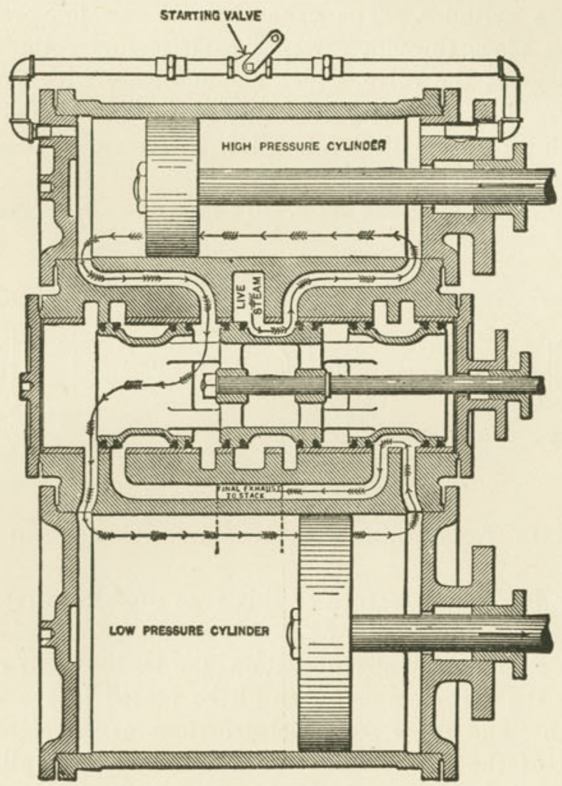


Fig. 18.

STEAM DISTRIBUTION IN BALANCED COMPOUND CYLINDERS.

Distribution of Steam. The distribution of steam is shown in Fig. 18. The live steam port in this design is centrally located between the induction ports of the high-pressure cylinder. Steam enters the high-pressure cylinder through the steam port and the central external cavity in the valve. The exhaust from the high-pressure cylinders takes place through the opposite steam port to the interior of the valve, which acts as a receiver. The outer edges of the valve control the admission of steam to the low-pressure cylinder. The steam passes from the front of the high-pressure cylinder through the valve to the front of the low-pressure cylinder, or from the back of the high-pressure to the back of the low-pressure cylinder. The exhaust from the low-pressure cylinder takes place through external cavities under the front and back portions of the valve, which communicate with the final exhaust port. The starting valve connects the two live steam ports of the high-pressure cylinder to allow the steam to pass over the piston.

Arrangement of Crank Axle. The crank axle necessarily con-

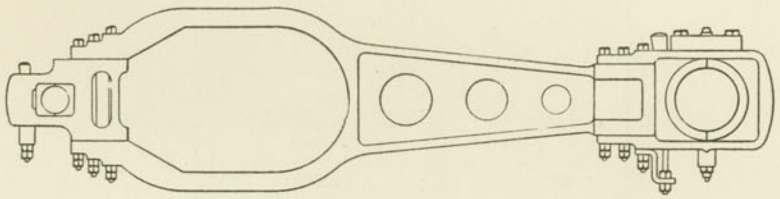


Fig. 19.

Inside Main Rods Used on Balanced Compound Engines.

stitutes an important feature of this type of locomotive. It may be made of a solid forging, or it may be made of a steel casting. The crank axle is generally placed on the leading pair of driving-wheels, as the cylinders can then all be placed in the same horizontal plane, and there are no obstructions to interfere with the movement of the inside main rods. This is accomplished on a 10-wheel or Atlantic type by making total wheel base a few feet longer than that of a similar single-expansion locomotive. The leading pair of driving-wheels is then moved back sufficiently to give the required length of the inside main rods. The outside main rods may be connected to either the first or second pair of driving-wheels. When they are connected to the first pair of wheels, the outside rods will usually be the same length as the inside rods.

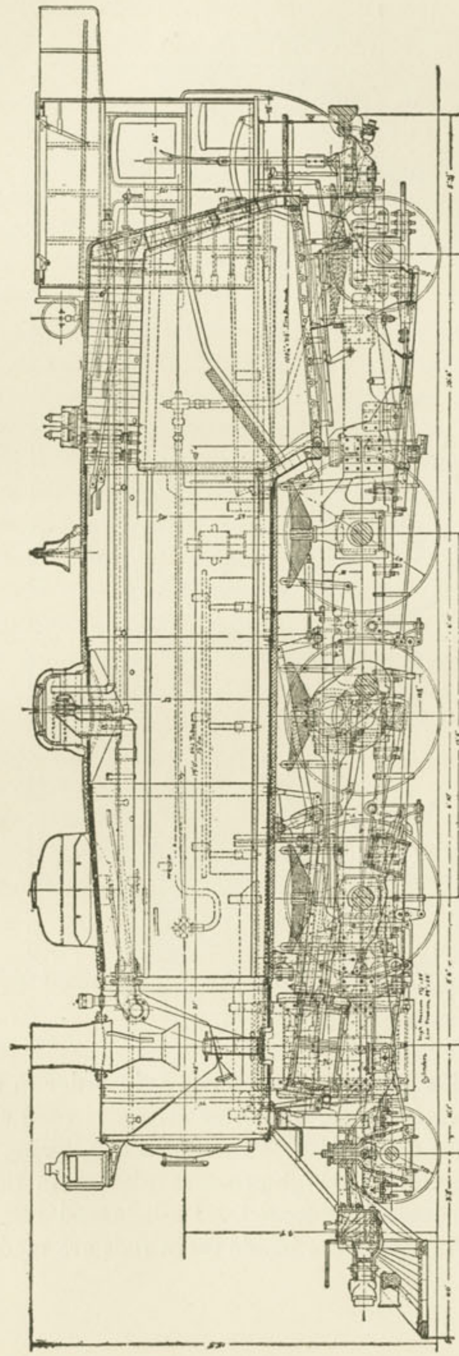


Fig. 20.

Longitudinal Section of Prairie Type Balanced Compound Locomotive.

(Baldwin Locomotive Works.)

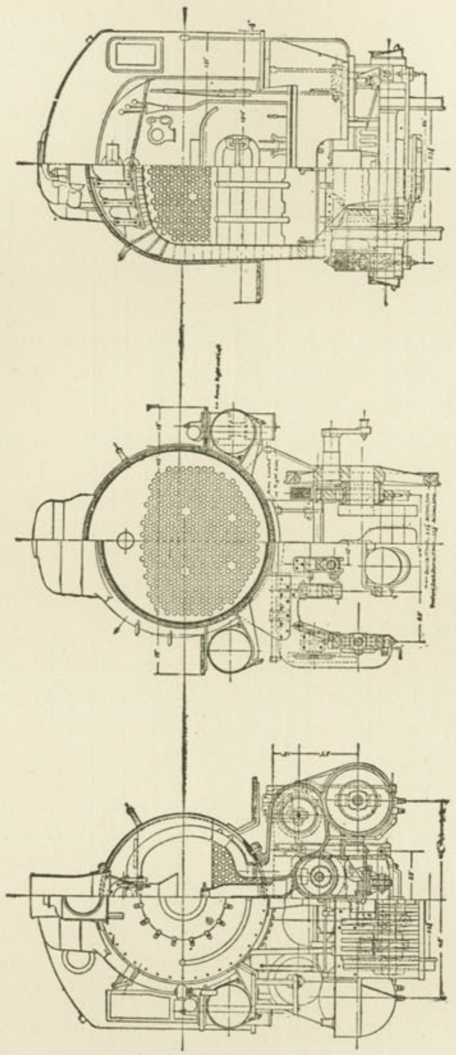


Fig. 21. Cross Sections of Prairie Type Baldwin Compound Locomotive.

Angularity of Inside Rods. In some cases, in order to reduce the angularity of the inside rods, a shorter stroke is used for the inside cylinders than for the outside. In other cases, owing to the impossibility of connecting the high-pressure pistons to the first axle, special arrangements are adopted. In balanced compound locomotives of the Pacific type, the inside main rods are made with

a loop or bifurcation, as shown in Fig. 19, which embraces the leading driving axle. On all the Baldwin engines of the balanced compound Pacific type the Stephenson link has been employed. The eccentrics are placed on the rear driving axle, and the link blocks are connected directly to the rock shafts. Since the eccentric rods with this arrangement are made rather long, they are provided with intermediate supports, thus avoiding all danger of buckling. With the Atlantic type using the Stephenson gear the eccentrics are placed on the second driving axle.

Atlantic Type of Balanced Compound. With the Atlantic type, which is equipped with the bifurcated rod in order to avoid lengthening the wheel base, the difficulty of placing the valve gear between the frames has been avoided by using the Walschaert motion. With this arrangement the center lines of the steam chest are placed outside the frames, the links are secured to rock shafts, whose bearings are bolted to the guide yoke, while the combining levers are placed inside the guides.

Prairie Type of Balanced Compound. With the Prairie type of balanced compound locomotives of the Baldwin design, the inside cylinders are inclined at an angle of seven degrees, as shown in Figs. 20 and 21, in order that the main rods may pass above the first driving axle. All the pistons are connected to the second pair of driving wheels. The piston valves are placed above the low-pressure cylinders in close proximity to the high-pressure cylinders. The two cranks on the same side of the engine are placed 173 degrees apart, so that the pistons start their strokes about the same instant and the balancing feature is retained. The Walschaert valve motion is used with this type of engine.

THE COLE FOUR-CYLINDER BALANCED COMPOUND.

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

Position of Cylinders for Different Types. To apply the four-cylinder balanced principle to the 4-4-2 or Atlantic type, 4-6-2 or Pacific type, 4-6-0 or ten-wheel type, 4-8-0 or twelve-wheel types, requires either the high-pressure cylinders to be located ahead of the low, with only a slight increase in length of wheel base or boiler; or an increase of 30 to 36 inches in the normal length between the front driver and the cylinder center. This also involves increasing the boiler and flues a like amount.

When applied to a locomotive having a two-wheeled leading truck, three different methods are available: (1) Locating the high-pressure cylinders ahead and increasing the distance between the front driver and center of cylinders about 24 inches; (2) inclining the high-pressure cylinders to clear the front driving axle; (3) looping the high-pressure main rods so as to encircle the front driving axle. These arrangements are given in their order of availability.

In considering the advantages of balanced locomotives, their use is not confined to high-speed passenger service. The destructive effect on the track is a matter of revolutions and not necessarily of speed. The dynamic effect of a medium size wheel, running at a high speed in revolutions, while making a moderate number of miles per hour, is just as great as that of a large wheel at the same number of revolutions, making a much higher speed in miles per hour.

Application of the Cole Compound on the Erie and Pennsylvania R. R. The Cole four-cylinder balanced compounds, used on the Erie and Pennsylvania Railroads, have the relative positions of the high and low-pressure cylinders, as shown in Figs. 22 and 23. The smoke-box steam pipes deliver steam into passages in the low-pressure saddle. It is brought to the forward part of the valve chamber to the high-pressure piston valves through encased elbow pipes, one of which is shown in elevation, Fig. 22. The high-pressure guides, Fig. 23, are located under and attached to the low-pressure saddle, whereas the low-pressure guides are in the usual location outside the frames. The cranks of the driving axles are 180 degrees apart, which places the reciprocating parts of the high and low-pressure engines in opposing motions, permitting perfect balance. In order to equalize the weights of the piston, those of the high-pressure cylinders are solid, and those of the low-pressure

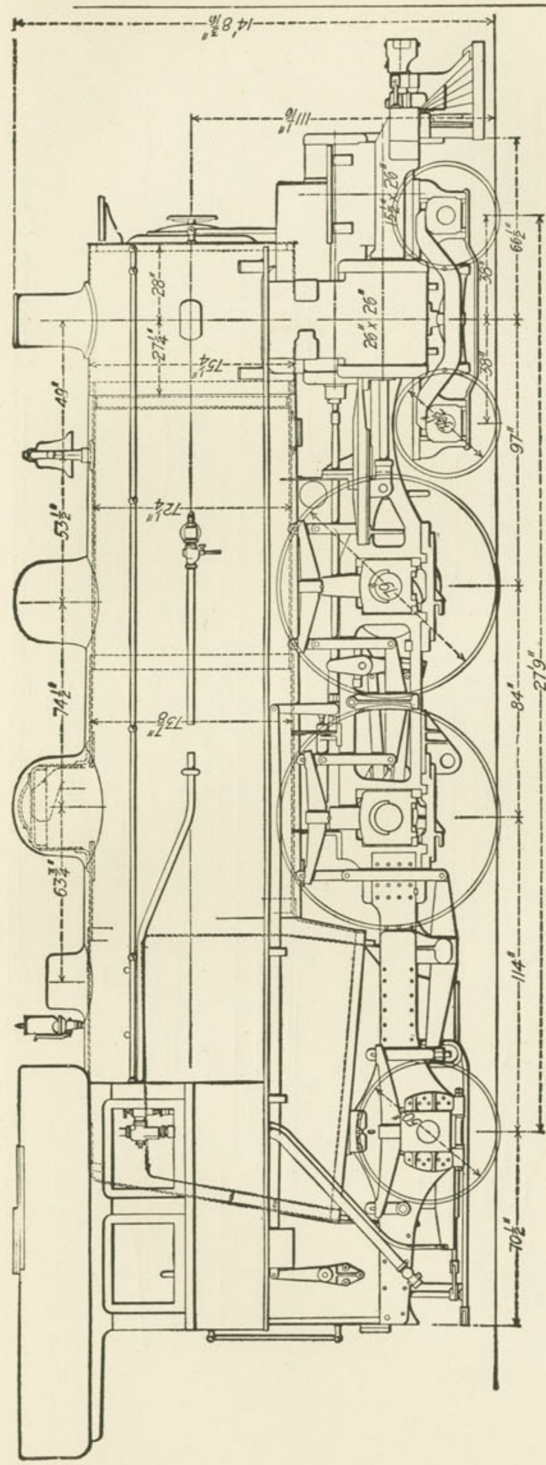


Fig. 22.—Side Elevation.

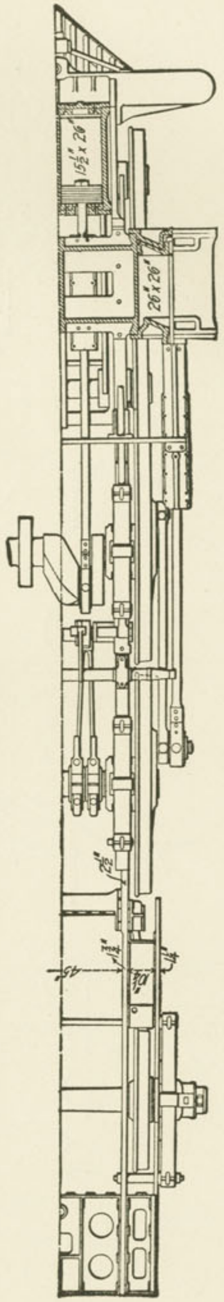


Fig. 23.—Half Plan.

Cole Four-cylinder Balanced Compound Passenger Locomotive, Atlantic Type. (American Locomotive Works.)

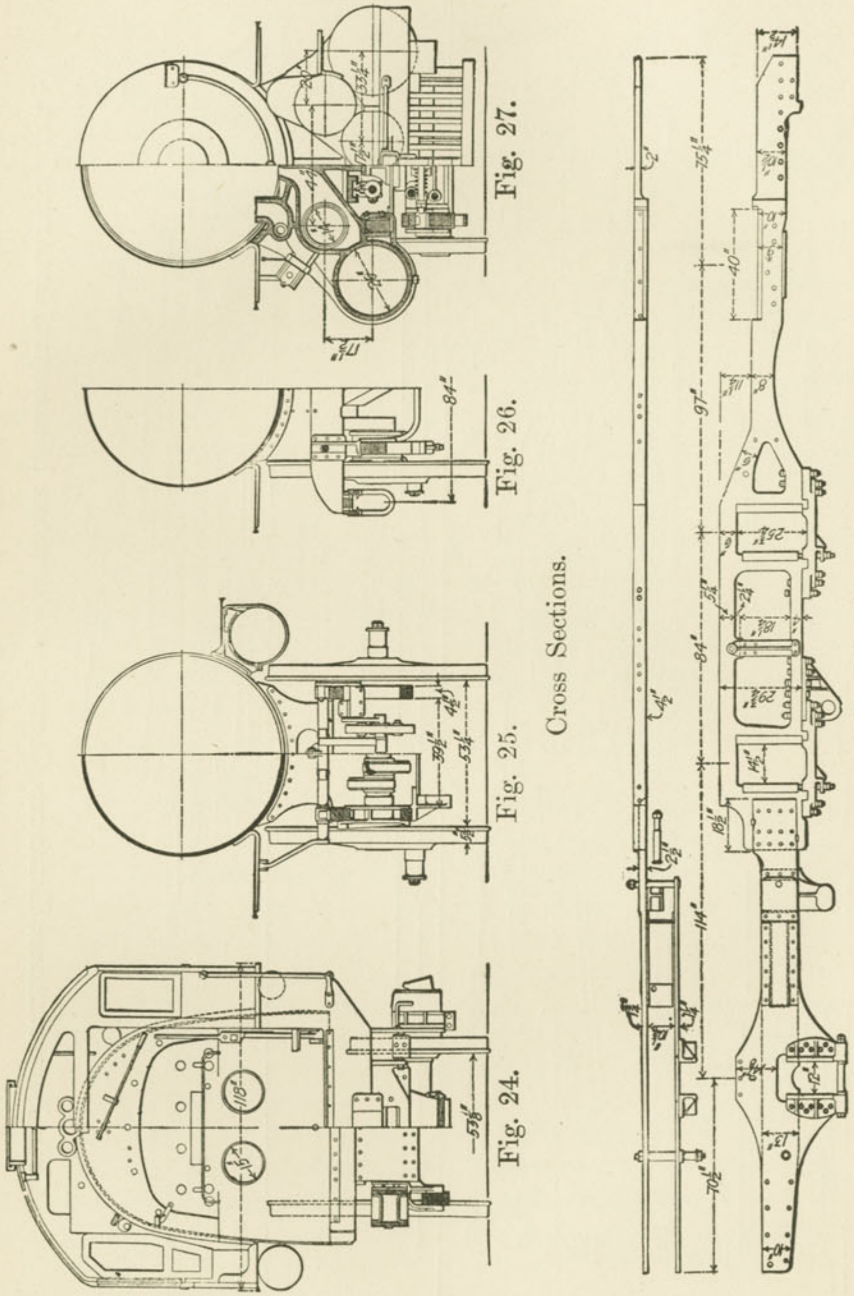


Fig. 24. Fig. 25. Fig. 26. Fig. 27.

Cross Sections.

Fig. 28.—Frames.

Cole Four-cylinder Balanced Compound Passenger Locomotive, Atlantic Type.

are dished and made as light as possible. A single valve motion of the Stephenson type operates a single valve stem on each side of the engine. Each valve stem carries two piston valves, one for a high and the other for a low-pressure cylinder. The back end, Fig. 24, and the two sections, Figs. 25 and 26, resemble the ordinary construction of two-cylinder locomotives, but the half front elevation and half section, Fig. 27, show a considerable difference

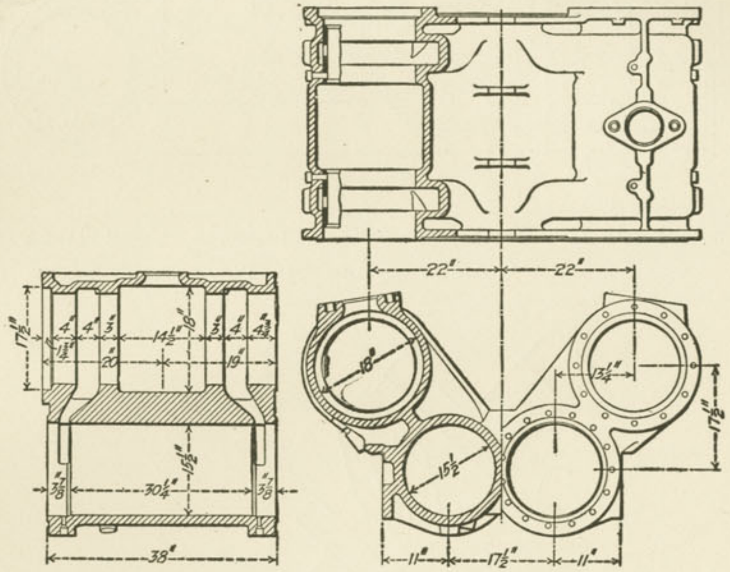


Fig. 29.

Arrangement of High Pressure Cylinders and Piston Valve Chambers, Cole Balanced Compound Locomotive.

of arrangement. The high-pressure piston rod, crosshead and guides are shown in position under the low-pressure saddle. Fig. 28 shows one of the frames in plan and elevation.

The main portion of the frame between the low-pressure cylinder and rear pedestal is of the bar type and very heavy. The forward extension in front of the low-pressure cylinder seat is slabbed, and to it are bolted the high-pressure cylinders. That

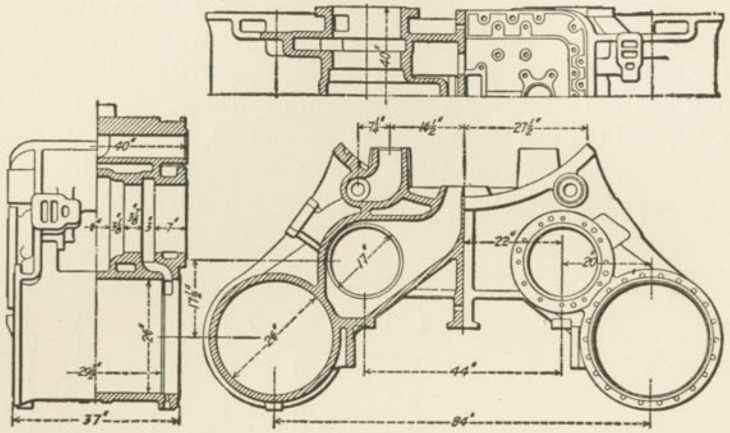


Fig. 30.

Arrangement of Low Pressure Cylinders, Cole Balanced Compound Locomotive.

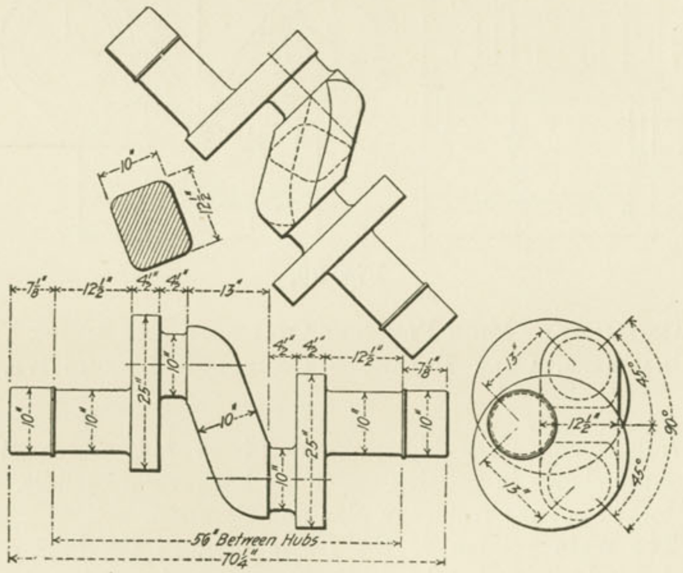


Fig. 31.

Crank Axle Used on Cole Balanced Compound Locomotives.

portion of the frame back of the rear pedestal is of double plate form, the additional plate, parallel to the main frame plate, being introduced in order to give proper support to the pedestals and springs of the outside journal-boxes of the trailing wheels.

The high-pressure cylinders and the high-pressure section of the piston valve chambers are all in one casting, as shown in Fig. 29. On the top of the valve chamber is the boss, in which the

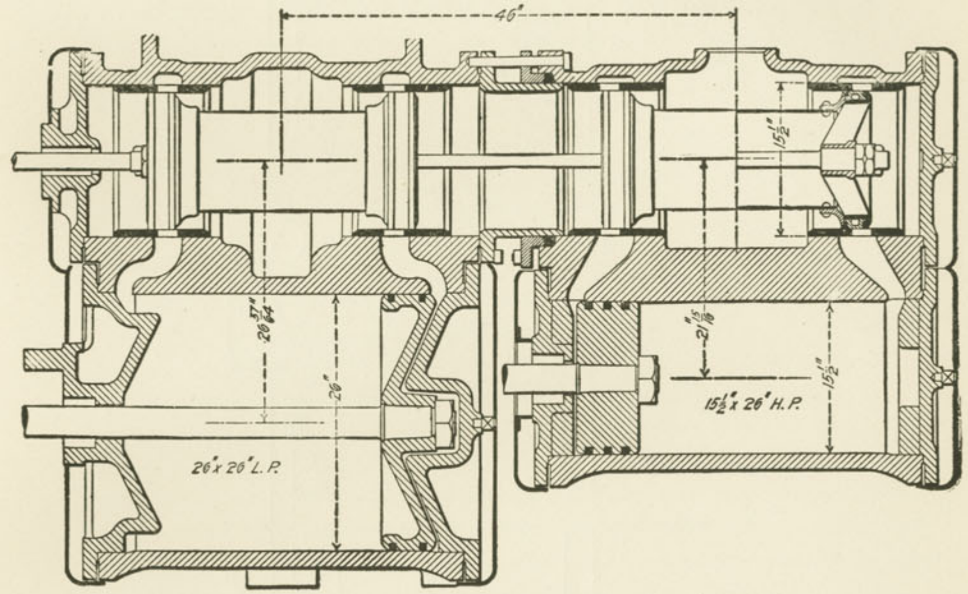


Fig. 32.

Arrangement of High and Low Pressure Cylinders of Cole Balanced Compound.

forward end of the elbow pipe is seated. The sides of the cylinder casting are faced off to the exact distance between the front plate extensions of the frames. The high-pressure valve chambers are in exact line with the valve chambers of the low-pressure cylinders, intermediate thimble castings and packing glands being inserted between the two to form a continuous chamber common to both the high and low-pressure cylinders, thus providing for expansion. Fig. 30 represents the low-pressure cylinders, which are cast separately and bolted together. In this case the inside of the cylinders are faced off to proper dimension to embrace the outer faces of the bar frames. The low-pressure piston valve chamber is in direct line between the cylinder and the exhaust base.

The crank axle is shown in Fig. 31. This type of crank axle

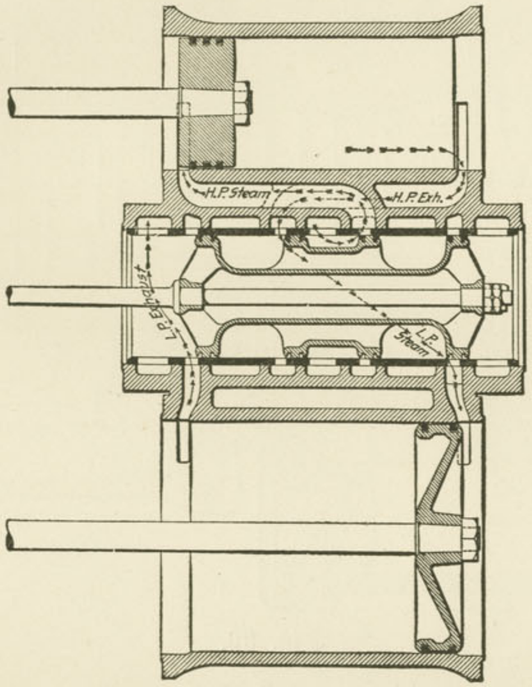


Fig. 33.

SINGLE VALVE USED FOR HIGH AND LOW PRESSURE CYLINDERS, COLE BALANCED COMPOUND LOCOMOTIVE.

permits of a very strong construction. The driving-box journal and the journal for the back end of high-pressure connecting rod are connected by a circular disc, which makes a very strong form of construction.

The high and low-pressure cylinders are shown in Fig. 32 as they would appear in section revolved in the same plane. The high-pressure valve is arranged for central admission and the low-pressure for central exhaust, both valves being hollow. A thimble casting, or ground joint ring, and a gland connect the two parts of the continuous valve chamber. The valves are exactly alike, with bodies of wrought-iron pipe, spiders and flanges of cast steel. The bull rings and packing rings, of which each valve has four, are of cast-iron.

When the cylinders are arranged in the same transverse plane, one valve may be used to control both the high and low-pressure cylinders. The valve, arrangement of ports and the direction of the steam from the high-pressure cylinder to the exhaust are shown in Fig. 33. The ports for the high-pressure cylinder are crossed, an arrangement which is used with considerable success on tandem compound engines.

SUGGESTIONS FOR RUNNING BALANCED COMPOUND LOCOMOTIVES.

In starting the locomotive with a train, place the reverse lever in full forward position, throw the cylinder cock lever forward, and open the starting valve, which allows live steam to pass to the low-pressure cylinder. The throttle is then opened, and as soon as possible when the cylinders are free of water and the train is under good headway the cylinder cocks and starting valve should be closed. As the economy of a compound locomotive depends largely on its greater range of expansion, the engineer should bear in mind that, in order to get the best results, he must use his reverse lever. After the starting valve is closed, and as the speed of the train inecreases, the reverse lever should be hooked back a few notches at a time until the full power of the locomotive is developed. If, after moving the reverse lever to the last notch, which cuts off the steam at about half-stroke in the high-pressure cylinder, it is found that the locomotive develops more power than is required, the throttle must be partially closed and the flow of steam to the cylinder reduced. On slightly descending grades the steam may be throttled very close, allowing just enough in the cylinders to keep the air valves closed. If the descent is such as to prevent the use of steam, close the throttle and move the reverse lever gradually to the forward notch and open the starting valve. This allows the air to circulate either way through the starting valve from one side of the piston to the other, relieves the vacuum and prevents the oil from being blown out of the cylinder. On ascending grades with heavy loads, as the speed decreases, the reverse lever should be moved forward sufficiently to keep up the required speed. If, after the reverse lever is placed in the full foward notch, the speed still decreases and there is danger of stalling, the starting valve may be used, admitting live steam to the low-pressure cylinders. This should be done only in case of emergency and the valve closed as soon as the difficulty is overcome.

The piston valves used on the balanced compound locomotives are arranged with inside admission to the high-pressure cylinders. The low-pressure ports are located in the ends of the casting. Hence it is more convenient to set the valves from the low-pressure ports, the high-pressure not being accessible. Both heads of the steam chest are removed, and with a tram, from some point on the body of the cylinder to the valve stem, the line and line positions of the valve on the low-pressure ports, in both front and back motion, are laid off and indicated by a prick punch mark on the valve stem. Using the same tram the position of the valve at different parts of the stroke can be ascertained, and the opening of the low-pressure ports noted, by the distance from the point of the tram to the prick punch mark. The relation of the valve to the high-pressure port must be ascertained by measurement, as in the case of an ordinary slide valve and its exhaust port.

DE GLEHN COMPOUND LOCOMOTIVE.

A number of ten-wheeled locomotives have recently been built by the Baldwin Works for the Paris-Orleans Railway of France. These engines, which have created considerable interest in this country, are compounded on the De Glehn System, and were built to drawings furnished by the railway company. All measurements in their construction were made on the metric system, necessitating the introduction by the builders of many new standards and gauges.

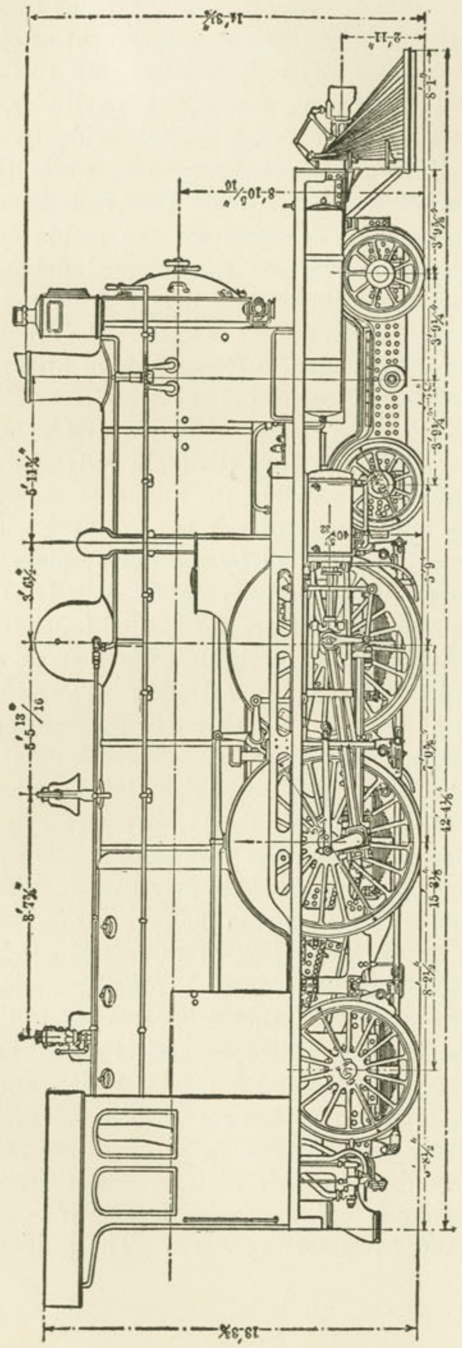


Fig. 34.

De Glehn Compound Locomotive Used on the Pennsylvania Railroad.

(American Locomotive Company.)

Arrangement of Cylinders. The De Glehn type of locomotive, shown in Fig. 34, is characterized by an arrangement of cylinders which divides the application of the power between two driving axles, and provides a separate valve gear for each cylinder, so that the high and low-pressure cut-offs can be independently varied. The high-pressure cylinders are placed outside, while the low-pressure are inside between the frames. The Welschaert valve motion is used throughout. The gears for the inside cylinders are driven from eccentrics placed on the forward driving axle, while those for the outside cylinders are driven from the second pair of driving-wheels by return cranks placed on the crank-pins.

General Method of Construction. The outside or high-pressure cylinders are connected to the second pair of driving-wheels, while the inside, or low-pressure, are connected to the first pair, which has a cranked axle. In order to keep the main rods of as nearly the same length and weight as possible, the high-pressure cylinders are set some distance in the rear of the low-pressure. This arrangement of cylinders is facilitated by the use of plate frames, to which the cylinder castings are conveniently bolted. In these locomotives the high-pressure cylinders are located immediately in front of the leading pair of driving-wheels. Each steam chest is cast in one piece with its corresponding cylinder. The slide valves are balanced and are of bronze. Both the low-pressure cylinders are formed in one casting, the upper part of which constitutes a saddle for the support of the smoke-box. The plate frames are cut out on each side, as the width over the low-pressure cylinders is greater than the distance between the frames. The low-pressure valves are also of bronze, but unbalanced; they have inclined seats, and their steam chests are formed within the cylinder casting. All the cylinders are set on an inclination of three and one-half per cent, this being done to provide clearance for the engine truck under the low-pressure cylinders. Steam is conveyed to the high-pressure cylinders through external pipes, and is passed on to the low-pressure cylinders through special valves, which are in the form of sleeves, with suitable openings cut in them. These valves may be rotated on their central axles by air pressure controlled from the cab, and according to their position the engine may be operated as a compound or single-expansion locomotive.

Construction of the Reciprocating Parts. The guides are of

forged steel and of the two-bar type. Those for the outside cylinders are braced by steel castings bolted to the frames, while the inside guides are secured to a heavy steel casting, which braces the frames between the high-pressure cylinders, and also forms a support for the low-pressure links. The crossheads are of wrought iron, case-hardened. Forged steel main and side rods are used throughout, the outside main rods being of I-section. The side rod stubs are of a modified strap form, the bolts being in one place with the straps. With this arrangement the bolts are in tension instead of shear. The return cranks for the outside valve motions are forged in one piece with the crank-pins, which are guided into their seats in the wheel centers by means of key-ways. By placing the center lines of the high-pressure steam chests outside the cylinder center lines, all parts of the valve motion can be located in the same plane. With the low-pressure cylinders such an arrangement is impossible, as the valves are driven by eccentrics which are placed on the first axle between the inside crank cheeks. The links, therefore, are mounted on rock shafts, which serve to transfer the motion from one plane to the other. These rock shafts are supported at three points, thus avoiding, as far as possible, any tendency to spring the valve motion. Independent reverse shafts are provided for the high and low-pressure valve gears, which may be operated together or separately by means of an ingeniously arranged screw reverse mechanism placed in the cab.

The driving-wheel centers are of cast steel with solid balances. The driving axles are of forged steel, the crank axle being forged in one piece. Wrought-iron driving boxes are employed, and the weight is transferred to the frames through underhung springs and forged steel equalizing beams. The engine truck side frames are of a slab form, placed inside the wheels. The weight is transferred to the truck through two hemispherical bearings whose centers are 35.43 inches apart, measured transversely. These bearings are seated in suitable castings, which can slide on a heavy cast steel crosstie. Lateral motion of the truck wheels is also provided, and is controlled by means of coiled springs. The center pivot supports no weight, and is used simply for pushing the truck. The truck frame is suspended directly on the springs, no equalizing beams being used.

Boiler Used on the De Glehn Compound Locomotive. The boiler is of the Belpaire type, built of steel plate, with the exception of the inside fire-box, which is of copper. The grate is placed between the frames, and is inclined toward the front at a sharp angle, thus giving an exceptionally deep throat. The stay-bolts in the water legs are of manganese bronze. Each bolt is drilled throughout its entire length with a hole six millimeters in diameter. These holes are closed up at their inner ends by riveting the bolts over after they have been screwed into the sheets. The fire-box is provided with a brick arch, which is supported on copper strips, secured to the side sheets by copper studs. The grate is of the rocking type. The tubes are soft steel, with internal ribs.

The boiler shell is built with longitudinal butt joints having double covering strips, while the circumferential seams are double-riveted with lap joints. The throat sheet completely encircles the barrel. The steam dome is built of flanged plate, with a full-sized opening in the barrel, and the base is strengthened by an inside liner. In accordance with general European practice, the throttle valve is of the sliding type, and is fitted with a pilot valve, which opens first. The pressure on the main valve is thus equalized, and it is more readily moved on its seat. The smoke-box is provided with a high variable exhaust nozzle, above which is placed a horizontal grating, composed of round rods set in a wrought-iron frame. The stack is of cast-iron, with a covering plate for checking the draft while the engine is standing. The locomotive is fitted with high-speed brake equipment furnished by the Westinghouse Air-brake Company of London, and also with steam-heating equipment. Screw couplings and spring buffers are provided at the front end of the locomotive and the rear end of the tender. The cab is built of steel plate, and has windows in the sides and front. An interesting part of the equipment is an arrangement which keeps a complete record of the speed throughout the run, and also shows the rate of speed at any instant. The motion for this device is derived from a stud which is screwed into the rear righthand crank-pin, and works in a slotted arm on a gear shaft located under the running board.

The tender is carried on six wheels, the two rear pairs of which are equalized. The frames are of the plate form, placed outside the wheels. Both the engine and tender are provided

with steps and handholds, and the gangways can be closed on each side by means of suitable gates.

One engine of this type has been run on the Pennsylvania Railroad, but with only moderate success. It was purchased by the Pennsylvania Railroad from the foreign railway. The principle of the balance compound follows so closely the lines of the De Glehn compound that it is doubtful if the latter type will ever become a factor in locomotive engineering in this country.

THE MALLET COMPOUND ENGINE.

This type of compound engine has come into extensive use in this country in recent years for heavy freight service. This type of engine permits compounding under the most favorable conditions. The high-pressure cylinders are placed at about the middle of the engine, while the low-pressure cylinders are attached to the forward or truck frames. The rear drivers are carried in frames rigidly attached to the boiler, and to these frames and to the boiler as well are attached the high-pressure cylinders. The forward drivers are not rigidly connected to the barrel of the boiler, but swivel radially from a center pin.

The steam dome is placed directly over the high-pressure cylinders, and steam is led from the dome down the outside of the boiler on either side to the high-pressure valve chambers. The steam, after being used in the high-pressure cylinders, passes to a jointed pipe between the frames, and is delivered to the low-pressure cylinders, whence it is exhausted by a jointed pipe through the stack in the regular way. The high-pressure valves are of the piston type, and the low-pressure cylinders are equipped with slide valves. The construction and arrangement of the flexible pipe connections between the high-pressure cylinder saddle and the low-pressure cylinder saddle are shown in Fig. 35. This pipe connection serves as a reservoir. It is divided into three sections, and is arranged with ball or slip joints so as to allow for its curvature and variation in length.

Features of the Mallet Compound Locomotive. The particular features of this type of locomotive are: the greater proportion of total weight that is distributed over a shorter rigid and a longer

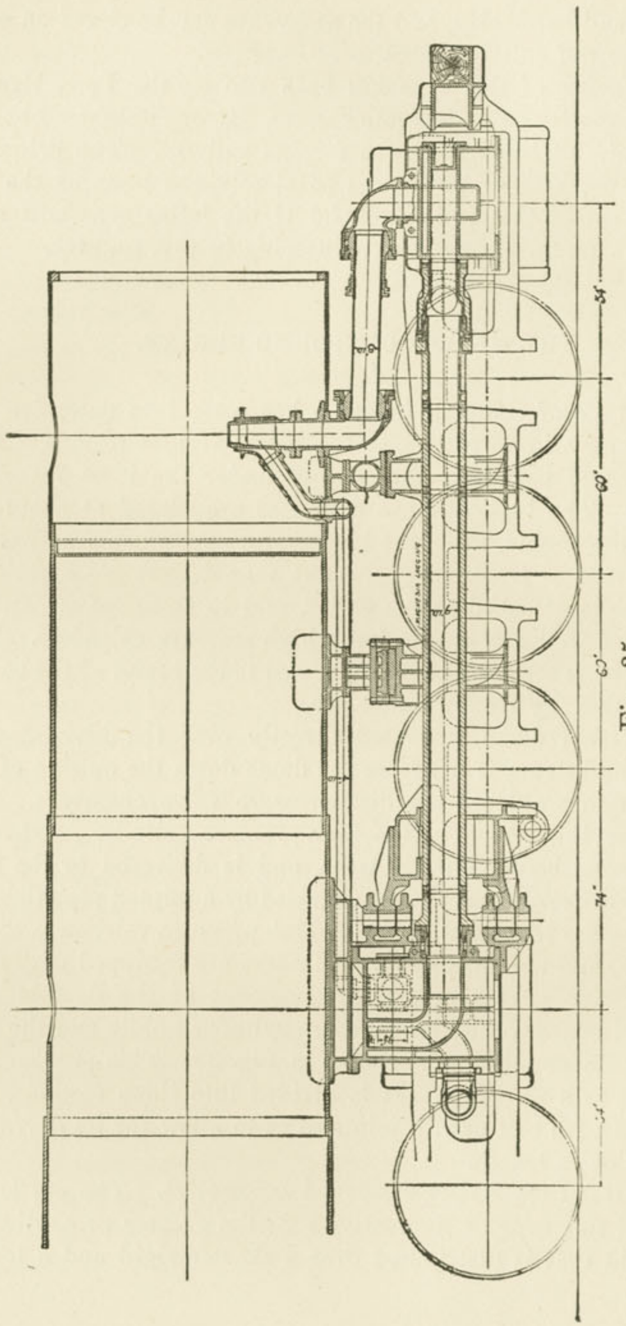


Fig. 35.

Central Longitudinal Section of Mallet Compound Engine from H. P. Cylinder to L. P. Cylinder, Showing Steam Pipes.

flexible driver wheel base; the comparatively low driver wheel loads; the relatively higher tractive power per unit of weight per wheel; the automatic regulation of the tractive efforts between two sets of engines; the distribution of the tractive power between two groups of driver wheel bases, running gear, frames and cylinders; the introduction of the compound practice with independent cylinders and large intermediate receiver capacity; the greater reserve capacity in the boiler, due to the use of a direct pressure steam in the low-pressure cylinder; the combination of extreme power in two sets of engines, with one boiler tender under the control of one engineer and fireman; a greater percentage of tonnage which can be hauled per total weight of locomotive and train, and less liability for complete disablement.

Comparison of the Mallet Compound with Other Types. This subject of the Mallet Compound engines, as used on American railways, was thoroughly discussed before the June, 1908, meeting of the American Railway Master Mechanic's Association, and the committee, after an exhaustive investigation, arrived at the following conclusions, which are based on a comparison of the Mallet Articulated Compound types of steam locomotives, now operating in road and helper freight service, with other designs of steam and electric locomotives performing similarly under relatively the same fuel, water and climatic conditions.

First. That for the greatest permissible tonnage and speed per train, on lines of considerable gradient and curvature, the Mallet Articulated Compound types of steam locomotives, either with or without leading and trailing trucks, and ranging in tractive power from 55,000 to 125,000 pounds, are relatively lower in first cost, and from performance to date more efficient and economical in operation and maintenance per unit of tractive power developed.

Second. That the Mallet Articulated Compound types of steam locomotives enable a practical improvement in the boiler efficiency by means of greater boiler capacity, increased reserve steam and water storage, larger grate area and fire-box and tube heating surface, prolonged passage of the products of combustion through the boiler, quickening circulation of the water in the boiler, heated feed water and reduced rate of draft and combustion.

Third. That the Mallet Articulated Compound types of steam locomotives give the practical opportunity to improve the engine efficiency by means of relatively greater tractive effort per pound of adhesive weight and from superheated higher initial, reheated receiver and lower terminal working steam pressure, due to the greater ratio of expansion that can be obtained in the cylinders, as well as through the use of a large intermediate receiver capacity, which is made possible by the four independent cylinders and their supply steam connections.

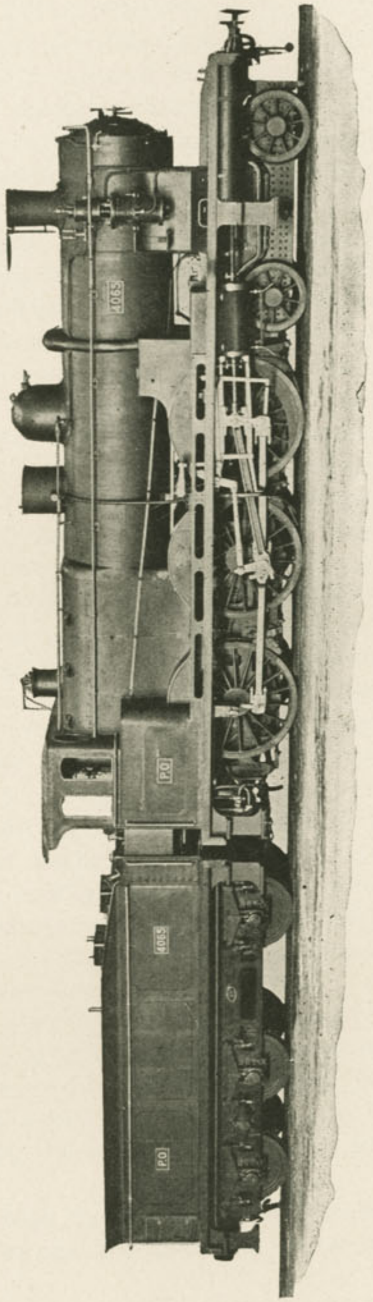
Fourth. That the Mallet Articulated Compound types of steam locomotives should have less depreciation, wear and failure of boiler and machinery through increased reserve capacity, reduced pressure of exhaust steam, more flexible wheel base, subdivision of power and stresses over a greater number of frames, cylinders, pistons, axles, crank-pins, rods and auxiliary parts; better balancing of the reciprocating and revolving mechanism, more uniform turning moment and less slipping of driving-wheels.

Fifth. That the Mallet Articulated types of steam locomotives, having relatively less non-adhesive weight per driving-wheel and a more uniform turning moment, with a reduction in unbalanced pressure at the driving-wheel and rail contacts, resulting in maximum adhesion, minimum slipping and a distribution of weight over a short rigid combined with a long flexible wheel base, will materially reduce the bridge, tie and rail strains and the tie and rail wear per unit of tractive power developed.

Sixth. That the Mallet Articulated types of steam locomotives, either for road or helper freight service, can materially increase the capacity of a given piece of track by fewer train movements and less congestion at terminals without increasing the acceleration or running speed above that which is permissible for efficient and economical heavy tonnage train movement, proper working super-elevation of curves, minimum rail wear and the least liability for derailment or accident.

Seventh. That the Mallet Articulated Compound types of steam locomotives will particularly place the movement of the traffic under the control of fewer persons, lessen the liability for complete disablement, and reduce the cost for engine and train crew hire, fuel, water, lubricants, stores, wiping, hostlering and dispatching.

Eighth. That the non-paying weight in motive power and supplies and the retarded movement and stalling of heavy tonnage



DE GLEHN TYPE OF COMPOUND ENGINE USED ON EUROPEAN RAILROADS
(Baldwin Locomotive Company)

trains will be minimized by the Mallet Articulated types of steam locomotives, especially through exceptionally long tunnels, where the permissible reversing of this type of locomotive will not subject the crew to the gases, smoke and heat from the exhaust.

Ninth. That the use of the Mallet Articulated Compound types of steam locomotive may permit of maintaining of progressively increasing the average gross tonnage per successive train movement between terminal yards to that which, consistent with the balancing of the motive power, distribution of cars and the accumulation of the traffic on the divisions, might give the desired capacity as well as efficiency and economy in the operation of a single piece of trunk-line track and its terminals, without making an expenditure on roadway to increase the weight limit, or for a reduction of grade, curvature or distance that would otherwise be necessary to accomplish the same result.

Tenth. That for service where it is essential to increase the tons moved per mile per hour per unit of cost by developing greater tractive power in one locomotive than what can be efficiently and economically produced by a consolidation or similar type, and where the use of self-contained motive power, proportion of adhesive to total weight, center of gravity, distribution of weight over driving-wheels, driving-wheel load, flexibility of driving-wheel base, and particularly the first cost, fixed charge, operating expense and reliability of service are elements of importance, the use of the Mallet Articulated Compound types of steam locomotives should receive careful consideration.

First Mallet Locomotive Used in the U. S. The first locomotive of the Mallet type which was put into operation in this country was for the Baltimore & Ohio Railroad, its object being to determine upon the practicability of such a class of motive power to efficiently and economically increase the capacity of a mountainous line requiring long and heavy freight service. The design of this experimental locomotive was completed in April, 1904, and, after having been exhibited at the Louisiana Purchase Exposition, was put into regular freight service in January, 1905.

The following essential features, which were at that time somewhat radical as compared with the ordinary American railroad practice, were as follows: The articulated frame; elimination of truck wheels; system of duplex compound; flexible joints to the receiver and exhaust pipes, as shown in Fig. 35; Walshaert motion gear; combination hand and power reversing gear; high-pressure piston and low-pressure double-ported slide valves; high and low-pressure high balanced piston packing rings; method of securing high-pressure cylinders to boiler.

After a number of years of constant use, this locomotive has demonstrated its availability in every particular. No difficulty has been experienced with any of the essential features mentioned above. The Walschaert valve gear, with which this engine is equipped, is the oldest of this type in use on any locomotive in this country, and it has demonstrated its superiority over other types of valve gears. The locomotive is doing the work of two standard Consolidation simple locomotives, and has given a horse-power as high as 2434 when running in simple gear, and 1906 when running in compound gear.

Among other types of Mallet Compounds which are being used are those on the Erie Railroad, the Great Northern Railway, Northern Pacific Railway, and the Chicago, Burlington & Quincy Railway. In every case the reports of these locomotives have been satisfactory, not only as regards performance, but also as regards economy of operation and the heavy loads which are handled.

Type of the Mallet Compound Used on the Erie R. R. In the type of Mallet Compound used on the Erie, the high-pressure cylinders are cast in pairs with saddles, the separation between the two cylinders being to the right of the center. This permits the intercepting valve to be placed in the lefthand cylinder casting, and also gives room for the connection to the receiver pipe. The exhaust steam from the right cylinder continues from the passage in its saddle to an outside U-shaped pipe connecting to a passage in the lefthand cylinder casting, which leads up to the intercepting valve chamber into which the exhaust steam from the left cylinder also passes. From this point the exhaust steam passes to a receiver pipe extending forward between the frames to the low-pressure cylinders. An extra exhaust connection is provided in the side of the left cylinder casting, which has a pipe leading to the exhaust pipe in the smoke-box. This connection is made by a pipe having universal joints in a manner similar to the receiver pipe. The construction of the receiver pipe is such as to permit free movement of the front frames in all directions, it being fitted with a ball joint at either end and a slip joint near the forward end. It is arranged to permit the locomotive to pass around 16-degree curves. The low-pressure cylinders are cast in pairs, the connection to the receiver pipe being made through a Y-shaped casting connecting at the back to the cored passages in the cylinder. The exhaust is carried through an elbow located on top, and in the center to a short pipe with universal joints leading to the exhaust pipe in the front end.

The high-pressure cylinders are fitted with piston valves having internal admission, while the low-pressure cylinders have balanced slide valves with external admission. The valve gear, which is of the Walschaert type, is so arranged that the return crank leads the pin in both sets, and hence the block is at the bottom of the link for the go-ahead motion for the low-pressure cylinders, and at the top of the link for the high-pressure cylinders. In this way the weights of the two valve gears counterbalance each other. The operation of reversing is further assisted by a pneumatic reversing device, which is connected to the reverse lever, and consists of two cylinders, one of which contains oil under pressure for locking the device in any desired position, the other cylinder being the air cylinder. The operation of this device is controlled from an auxiliary reversing lever in the cab.

The remarkable success which has attended the use of Mallet Compounds in heavy pushing service has been the principal claim to superiority of the compound engine over the simple locomotive, and has again attracted considerable attention to the advantages of the compound type.

Mallet Articulated Compound Locomotives, for the Southern Pacific Company. The Baldwin Locomotive Works have recently completed, for the Southern Pacific Company, two Mallet articulated compound locomotives, which are the heaviest engines thus far built for any railway. These locomotives have eight coupled wheels in each group, and, in accordance with the previous practice of the builders, are equipped with two-wheeled leading and trailing trucks. The constructive details embody various features of special interest. The calculated tractive force of this design is 94,640 pounds. The locomotives will be used on the Sacramento Division between Roseville and Truckee, where the maximum grade is 116 feet per mile, and the rating 1212 tons of cars and lading.

The boiler is straight topped, 84″ in diameter, and is equipped for oil burning. The fire tubes are 21 feet long. They terminate in a combustion chamber, 54 inches long, in front of which is a feed water heater 63 inches in length. The tubes in the feed water heater are set in alignment with the fire tubes, and are equal to them in number and diameter. Two non-lifting injectors are provided, and they discharge, right and left, into the feed water heater chamber, which is kept constantly filled with water. The feed passes out through the top of the chamber, and is then delivered into the main barrel through two checks, placed right and left immediately back of the front tube sheet. A superheater, placed in the piping system between the high and low-pressure cylinders, is located in the smoke-box. The combustion chamber is provided with a man-hole, so that the tube ends are readily accessible.

In order to facilitate repairs, the boiler is provided with a separable joint, which is placed at the rear end of the combustion chamber. The joint is effected by riveting a ring to each boiler section and uniting the rings by 42 bolts, 1¼ inches in diameter. The rings are butted with a V-shaped fit.

The waist-bearer under the combustion chamber is bolted into place, while the front waist-bearer and the high-pressure cylinder saddle are riveted to the shell. The longitudinal seams in the barrel are placed on the top center line, and have "diamond" welt strips inside. Flexible staybolts are liberally used in the sides, back and throat of the firebox, while the crown sheet is stayed with T-irons hung on expansion links, in accordance with Associated Lines practice.

The dome, which is of cast steel, is placed immediately above the high-pressure cylinders, and the arrangement of the throttle and live steam pipes is similar to that used on heavy articulated locomotives previously built. The exhaust from the high-pressure cylinders passes into two pipes, which lead to the superheater. These pipes are of steel, and each is fitted, at the back end, with a slip joint made tight with a packed gland. The steam enters the superheater at the front end of the device, and passes successively through six groups of tubes. It then enters a T-connection, from which it is conveyed to the low-pressure cylinders through a single pipe having a ball joint at each end and a slip joint in the middle. Each low-pressure cylinder is cast separately and is bolted to a large steel box casting, which is suitably cored out to convey the steam from the receiver pipe to a pair of short elbow pipes, making final connection with the low-pressure steam chests. The distribution is here controlled by 15-inch piston valves, which are duplicates of those used on the high-pressure cylinders. The final exhaust passes out through the front of each casting into a T-connection, which communicates with a flexible pipe leading to the smoke-box. The slip joint in this pipe is made tight by means of snap rings and leakage grooves. At the smoke-box end, the ball joint is fitted with a coiled spring, which holds the pipe against its seat. The valves for both the high and low-pressure engines are set with a travel of 5½ inches and a lead of five-sixteenths inches. The steam lap is one inch, and the exhaust clearance $\frac{1}{16}$ inch. The high-pressure cylinders are oiled from a lubricator placed in the cab, while a force feed pump, driven from the forward valve motion, is provided for the low-pressure cylinders. This arrangement obviates the use of flexible oil pipe connections.

Reversing is effected by the Raggonet power gear, which is operated by compressed air and is self-locking. The gear is directly connected to the high-pressure reverse shaft. The reach rod connection to the low-pressure reverse shaft is placed on the center line of the engine, and is fitted with a universal joint located immediately above the articulated frame connection. The joint is guided between the inner walls of the high-pressure cylinder saddle. In this way the reversing connections are simplified, and when the engine is on a curve the angular position of the reach rod has practically no effect on the forward valve motion.

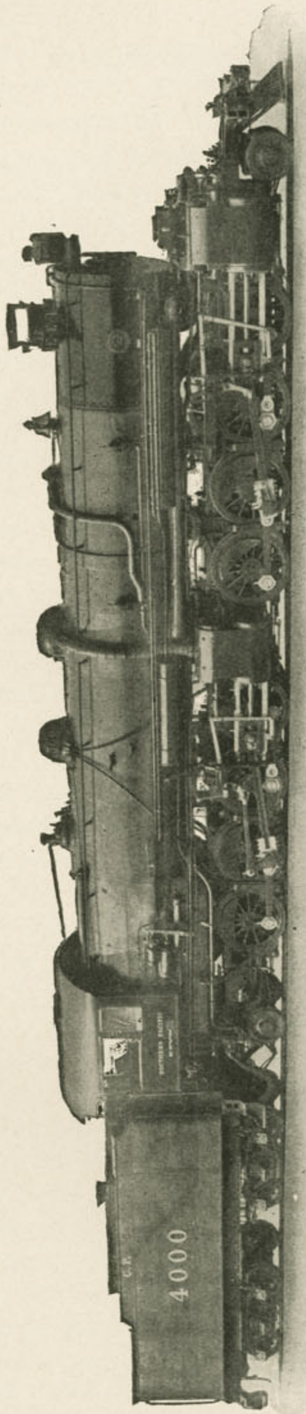
Some of the locomotives are equipped with vanadium steel frames, and others with frames of carbon steel. The connection between the frames is single, and is effected by a cast steel radius-bar, which also constitutes a most substantial tie for the rear end of the front frames. The fulcrum pin is 7 inches in diameter; it is inserted from below, and held in place by a plate supported on a cast steel crosstie, which spans the bottom rails of the rear frames between the high-pressure cylinders. The weights on the two groups of wheels are equalized by contact between the front and rear frames, no equalizing bolts being used in this design.

The front frames are stopped immediately ahead of the leading driving pedestals, where they are securely bolted to a large steel box casting, previously mentioned, which supports the low-pressure cylinders. The cylinders are keyed at the front only. The bumper beam is of cast steel, 10 feet long, while the maximum width over the low-pressure cylinders is approximately 11 feet.

The boiler is supported on the front frames by two bearings, both of which have their sliding surfaces normally in contact. The front bearing carries the centering springs, and the wear is taken, in each case, by a cast iron shoe 2 inches thick. Both bearings are fitted with clamps to keep the frames from falling away when the boiler is lifted.

These locomotives naturally embody in their design many smaller details of interest. The cylinder and steam chest heads are of cast steel, the low-pressure heads being dished and strongly ribbed. The low-pressure pistons are also dished; they have cast steel bodies, and the snap rings are carried by a cast iron ring which is bolted to the body and widened on the bottom. The links for the low-pressure valve gear are placed outside the second pair of driving wheels, and are supported by cast steel bearers which span the distance between the guide yoke and the front waist bearer. The low-pressure valve stems are connected to long cross-heads, which slide in brackets bolted to the top guide bars. The locomotive is readily separable, as the joint in the boiler is but a short distance ahead of the articulated frame connection, and all pipes which pass the joint are provided with unions. The separable feature was tested by the builders, and proved entirely feasible. Sand is delivered to the rear group of driving wheels from a box placed on top of the boiler, and to the front group from two boxes placed right and left ahead of the leading drivers.

The tender is designed in accordance with Associated Lines standards, and is fitted with a 9000 gallon water-bottom tank. The capacity for oil is 2850 gallons. The trucks under both the locomotive and tender are equipped with "Standard" solid forged and rolled steel wheels.



LARGEST LOCOMOTIVE IN THE WORLD
MALLET ARTICULATED COMPOUND LOCOMOTIVE, USED BY THE SOUTHERN PACIFIC
(Baldwin Locomotive Works)

The detail parts of this locomotive have, where possible, been designed in accordance with existing standards of the Associated Lines. The engine is practically equivalent, in weight and capacity, to two large Consolidation type locomotives, and, in spite of its great size, presents a pleasing and symmetrical appearance. The following table will give the principal dimensions of these locomotives:

SOUTHERN PACIFIC MALLET COMPOUND LOCOMOTIVE.
(BUILT BY BALDWIN LOCOMOTIVE WORKS.)

Gauge,	4′ 8½″
Cylinders,	26″ & 40″ x 30″
Valves,	Balanced Piston.
Boiler.	
Type,	Straight.
Material,	Steel.
Diameter,	84″
Thickness of sheets,	$\frac{13}{16}$″ & $\frac{27}{32}$
Working Pressure,	200 lbs.
Fuel,	Oil.
Staying,	⊥ Crown Bars.
Fire Box.	
Material,	Steel.
Length,	126″
Width,	78¼″
Depth, front,	75½″
" back,	70½″
Thickness of sheets, sides,	⅜″
" " " back,	⅜″
" " " crown,	⅜″
" " " tube,	½″
Water Space,	
Front,	5″
Sides,	5″
Back,	5″
Tubes.	
Material,	Steel.
Thickness,	.125″
Diameter,	2¼″
Number of Fire Tubes,	401
Length " " "	21′ 0″
No. Feedwater Heater Tubes,	401.
Length " " "	5′ 3″

Heating Surface.	
Fire Box,	232 sq. ft.
Fire Tubes,	4941 sq. ft.
Feedwater Heater,	1220 sq. ft.
Total,	6393 sq. ft.
Grate Area,	68.4 sq. ft.
Driving Wheels.	
Diameter, outside,	57″
" center,	50″
Journals, main,	11″ x 12″
" others,	10″ x 12″
Engine Truck Wheels.	
Diameter, front,	30½″
Journals,	6″ x 10″
Diameter, back,	30½″
Journals,	6″ x 10″
Wheel Base.	
Driving,	39′ 4″
Rigid,	15′ 0″
Total Engine,	56′ 7″
Total Engine and Tender,	83′ 6″
Weight.	
On Driv. Wheels,	394,150 lbs.
On Truck, front,	14,500 lbs
On Truck, back,	17,250 lbs.
Total Engine,	425,900 lbs.
Total Engine & Tender, about	596,000 lbs.
Tender.	
Wheels, Number,	8.
" Diameter,	33½″
Journals,	6″ x 11″
Tank Capacity, water,	9,000 gals.
Tank Capacity, oil,	2,850 gals.
Service,	Freight.

Engine equipped with Baldwin Smoke Box Superheater.
Superheating Surface, 655 sq. ft.

OPERATION OF COMPOUND LOCOMOTIVES.

Compound locomotives differ from the ordinary type in that a simple engine has but one set of cylinders of the same diameter and uses the steam but once, while a compound or double-expansion engine has either two or four cylinders of varying diameters, and the steam, after passing through the first set and losing part of its energy, passes into the second set of cylinders, where a certain amount of its remaining energy is used.

One cylinder on a compound locomotive is called the high-pressure cylinder and the other one the low-pressure cylinder, because the high-pressure cylinder takes its steam directly from the boiler at nearly initial boiler pressure, while the low-pressure cylinder, under ordinary conditions, receives the steam from the high-pressure cylinder only, and at a greatly reduced pressure.

The principal advantage claimed for compound locomotives is economy in the consumption of fuel and water. A compound engine in good order and properly operated does more work with a given volume of steam than a simple engine.

In the Schenectady two-cylinder compound, the duty of the oil dash-pot is to insure a steady movement of the valve without shock. The oil dash-pot should be kept full of engine oil to prevent intercepting valve from slamming. Failure or breakage of intercepting valve can nearly always be traced to lack of oil in dash-pot.

To operate the Schenectady two-cylinder compound as a simple engine, the handle of the three-way cock in the cab is moved by the engineer so as to admit either air or steam pressure into the pipe which connects with one end of the separate exhaust valve chamber, forcing the separate exhaust valve, which is otherwise held in normal position by a spring, from right to left and in the direction of the intercepting valve. Then, as the throttle is opened, steam is admitted directly from the boiler into the passage which communicates with the intercepting valve, forcing the valve from left to right and permitting the steam to pass through it, and leading it through suitable ports and passages, whence it passes through the reducing valve to the low-pressure steam chest. At the same

time steam is admitted directly from the high-pressure cylinder to the atmosphere through the receiver and separate exhaust passage, while steam from the low-pressure is exhausted directly to the atmosphere.

A Schenectady compound should be operated as a simple engine only at very low speeds, when there is danger of stalling, and in starting very heavy trains. It should not be run simple when running faster, because it would mean not only a waste of steam and greater consumption of fuel, but also a greater and unnecessary wear and strain on the machinery.

To change a two-cylinder compound from simple to compound, the three-way cock would have to be returned to the normal position, which permits the pressure to be withdrawn from the piston head of the separate exhaust valve. As this pressure is exhausted to the atmosphere, the compressed spring is released and forces the separate exhaust valve to normal position, closing communication. The pressure in the receiver, due to the exhaust from the high-pressure cylinder, will rise and force the intercepting valve to the left, which opens the passage for the exhaust steam from the high-pressure cylinder through the receiver to the low-pressure steam chest. The movement of the intercepting valve to the left shuts off the live steam between the boiler and the low-pressure steam chest. The intercepting valve is automatically operated by the steam pressure exerted upon it, due to the difference in areas of the ends of the valve.

A compound locomotive should be lubricated so as to feed two-thirds of the oil to the high-pressure cylinder while using steam and one-third to the low-pressure cylinder. When drifting long distances, about two-thirds of the oil should be fed to the low-pressure cylinder, owing to the greater surface exposed in the low-pressure cylinder and the imperfect distribution of oil due to the absence of steam from the cylinders.

More oil is fed to the high than to the low-pressure cylinder, because part of the oil fed to the high-pressure cylinder is carried along with the steam to the low-pressure cylinder, and the high pressure of steam in the high-pressure cylinder causes more friction than exists in the low-pressure cylinder. The greater the pressure the greater the friction, consequently more oil is needed to counteract that friction, and because the higher temperature and pressure in the high-pressure cylinder produce more friction, therefore more oil is required for perfect lubrication. As a certain amount of the oil fed to the high-pressure cylinder is carried along with the steam to the low-pressure cylinder, less need be fed directly to the low-pressure cylinder.

Just enough water should be carried in a boiler of a compound locomotive to guarantee absolute safety from overheating the fire-box under all conditions of service, in order to assure the delivery of dry steam to the cylinders, as wet steam is particularly injurious to compound locomotives.

Compound locomotives should always be started in simple position when pulling a long train. When drifting, the three-way cock in cab should be in the same position as when working the engine simple, which causes the separate exhaust valve to open. The cylinder and port cock should also be open. Steam blowing at the three-way cock indicates a leaky separate exhaust valve seat and steam passing by the exhaust valve piston packing rings.

If the engine will not operate as compound when air pressure on the separate exhaust valve is released by the three-way cock, it indicates that the separate exhaust valve is stuck, and communication with the separate exhaust valve has not been closed. A small quantity of kerosene admitted through the oil plug at the three-way cock and forced to the separate exhaust valve will generally release the valve.

If the engine stands with the high-pressure side on the dead-center, and will not move when given steam, the trouble is due to the intercepting or reducing valve sticking, which prevents direct communication between the boiler and low-pressure cylinder. The position of the intercepting valve stem will indicate which valve is sticking. If the stem extends clear out, it would be the intercepting valve; and, unless some of the posts were broken, a light tap on the end of the stem after the throttle is open will send it ahead. If the stem protrudes only a few inches, it will be the reducing valve that is sticking. Usually a few sharp blows on the intercepting valve back head with the throttle open will dislodge it, and direct communication between the boiler and the low-pressure cylinder will be again established.

In the event of a breakdown, open the separate exhaust valve

as when running simple; then block, cover ports and disconnect the same as with a single-expansion engine.

To shut off steam pressure from the steam chest and low-pressure cylinder, the separate exhaust valve and intercepting valve should be placed in position to allow the engine to work as a single-expansion engine.

It is important that air be pumped up on a Schenectady two-cylinder compound locomotive before the engine is moved, in order to insure a sufficient amount of air pressure to operate the separate exhaust valve, so that the engine can be operated as a single-expansion.

To locate blows or leaks through valves or cylinder packing on two-cylinder compounds, tests are made precisely as with a single-expansion engine. Engine should be worked as a simple engine while testing for such blows. To test blows in intercepting valve, place right-hand crank pin on top quarter and the reverse lever in the center of sector, close intercepting valve, and open separate exhaust valve as when working simple. Steam will pass through the separate exhaust valve and appear at the exhaust nozzle if the intercepting valve blows.

The by-pass valves are connected to the steam ports, and furnish communication between steam chest and steam ports in cylinder. They are used to relieve the cylinder from excessive back pressure when drifting.

Compound locomotives are called tandem compounds when the high-pressure cylinder is ahead of and connected with the low-pressure cylinder, and both pistons are operated by the same piston rod. The steam in a tandem compound locomotive exhausts from the high-pressure cylinder and passes over to the low-pressure cylinder on the same side of the engine.

The valves on a tandem are designed for both inside and outside admission. On the high-pressure cylinder the valves are arranged for internal admission, and the steam ports in the high-pressure cylinder are crossed. On the low-pressure the valves are arranged for external admission, and the steam ports are those in use on the ordinary type. Since both valves operate on one stem, and as the high-pressure valve is internal, and the low-pressure external, admission, the ports in the high-pressure cylinder must necessarily be crossed, so that when live steam is admitted to one end of the high-pressure cylinder the exhaust from the opposite end of the high-pressure can pass over into the low-pressure cylinder to exert its energy in the same direction and in unison with the high-pressure. Steam leaving the high-pressure valve and entering the back port in the high-pressure cylinder flows to the forward end of the cylinder, forcing the piston back. After spending its force it is exhausted to the high-pressure steam chest, passing through the center of the hollow high-pressure valve to the outer back edge of the low-pressure valve, enters the back end of the low-pressure cylinder, and, after spending its force, escapes through the exhaust port of the low-pressure valve directly to the atmosphere.

A tandem compound should be operated as a simple engine only in starting, or when there is a possibility of stalling. It can only be operated as a simple engine when the starting valve is used. The starting valve, which is operated by a lever in the cab, admits live steam directly to the low-pressure cylinder in the following manner: Steam is admitted to the high-pressure steam chest through the short steam pipe connecting saddle and chest, passing through suitable ports and around by-pass valves which register with the high-pressure steam ports. The by-pass valves are held against their seats by the pressure from below, which is in direct communication with the chest. The starting valve having thus established communication with both high-pressure steam ports, steam passes through both hollow piston valves and is admitted to the low-pressure cylinder.

REVIEW QUESTIONS.

COMPOUND LOCOMOTIVES.

1. What is the principal object in compounding a locomotive?

2. What reasons can you give why compound locomotives have not been more generally used?

3. Name four different types of compound engines which have had general use in this country.

4. What are the distinctive features of a Vauclain compound engine?

5. What types of compound locomotives are being more extensively used at the present time?

6. Explain the functions of the intercepting valve in a compound engine.

7. Why are the air valves placed in the steam passages of low-pressure cylinders of a Vauclain compound?

8. Describe the usual precautions which are necessary when running a Vauclain Compound.

9. How does the cross compound locomotive differ from the Vauclain compound?

10. What are the advantages and disadvantages of a cross compound locomotive?

11. What is the principal difference between a Baldwin cross compound locomotive and a Schenectady cross compound locomotive?

12. When the Schenectady cross compound engine is running simple, how is it changed to running compound?

13. What are the principal advantages and disadvantages of the tandem compound locomotive?

14. For what kind of service have tandem compounds been principally used?

15. Describe the arrangement of cylinders of a balanced compound locomotive.

16. Name four advantages of four-cylinder balanced compound locomotives.

17. How are the cranks connected in a balanced compound locomotive so as to properly balance the reciprocating parts?

18. To what part of the locomotive are the high-pressure cylinders of a balanced compound engine connected? To what part are the low-pressure cylinders?

19. If it is not possible to connect the low-pressure connecting rods to the front crank axle, how is the motion of the piston transferred to the locomotive wheels?

20. Describe what method is used in the Prairie type of the Baldwin balanced compound when connecting the connecting rods to their respective crank-pins.

21. Describe the general arrangement of cylinders in a Cole four-cylinder balanced compound.

22. How are balanced compound locomotives started, and how should the different levers be arranged after the engine has attained its normal speed?

23. Suppose the reverse lever was in the last notch, and it was found that the locomotive developed more power than was required, what would you do to cut down the speed?

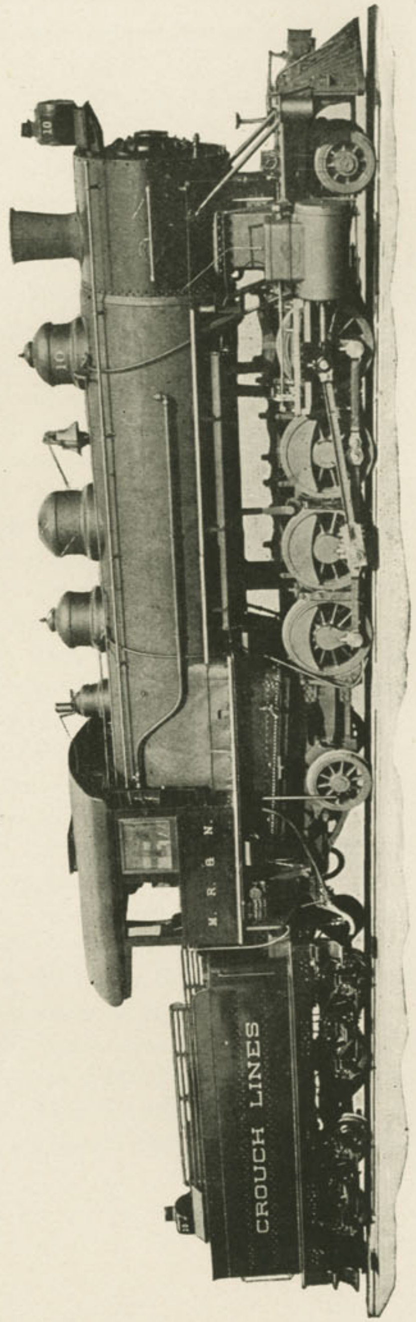
24. What are the principal advantages of the Mallet Compound engine?

25. How are the cylinders arranged on the Mallet Compound engine?

26. How does the Mallet Compound compare with other types of locomotives in general use?

27. Name some of the features of a Mallet Compound which are different from those of any other design.

28. Describe the arrangement of the pipe connections between the high-pressure and low-pressure cylinder of a Mallet Compound engine.



MIKADO, OR EIGHT-COUPLED, TYPE OF LOCOMOTIVE, USED FOR HEAVY FREIGHT SERVICE ON THE MISSOURI RIVER & NORTHWESTERN RAILROAD
(Baldwin Locomotive Works)

Valves and Valve Gear

Of all the various parts of a locomotive, the valve and valve gear are the most interesting and most important with which an engineer has to deal. Unless the functions of admission, cut-off, expansion, release and compression be thoroughly understood, the valve cannot under varying conditions be set to give the best results of the engine under those conditions.

The function of the valve or valves of a steam engine is tc admit steam from the boiler to one side of the piston, while the exhaust from the other side is permitted to escape into the atmosphere. The valve must also close the admission of steam at the point necessary to give the expansion desired, and it must close the exhaust port at such a point in the return stroke that when the return stroke is completed there may be caught between the piston and the head of the cylinder a certain amount of steam to serve as a cushion to the reciprocating parts of the engine.

All locomotive valves receive their motions from eccentrics or cranks, which are transmitted to the valve by means of rockers and links, the whole mechanism being called the valve gear of the engine. The two types of valves in general use are the slide valve and the piston valve.

There are various terms which are used when considering the subject of valves which must be understood before an intelligent discussion of the subject of valve setting can be entered into.

Admission. The period during which the steam passages from the valve chest to the cylinder are open, and steam of initial pressure is admitted behind the piston.

Exhaust. The period during which the exhaust passages are open and steam is exhausted from the cylinder.

Cut-off. The point in the stroke at which the steam port closes. When the valve is cutting off, it takes the position shown in Fig. 1. The valve is just covering the port, as shown by the arrow.

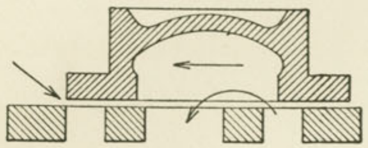


Fig. 1.

CUT-OFF.

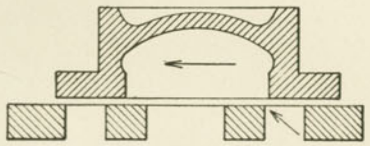


Fig. 2.

COMPRESSION.

Expansion. The period during which the steam expands in the cylinder, beginning at the point of cut-off, and continuing until the steam is released or the exhaust port is open.

Compression. The period during which the steam is compressed, which occurs from the time the exhaust port closes until

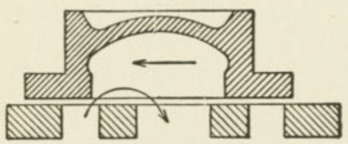


Fig. 3.

RELEASE.

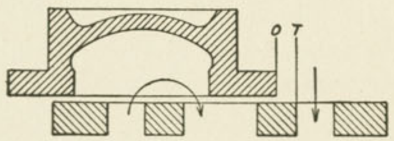


Fig. 4.

OVERTRAVEL.

the end of the stroke. A small portion of the steam is thus retained in the cylinder to be compressed by the advancing piston, which thus meets with a slight cushion at the end of the stroke, and all shock and jar are thus prevented. This point of compression begins when the inside or exhaust edge of the valve has closed the exhaust port, as shown in Fig. 2.

Release. Release occurs when the exhaust edge of the valve opens the steam port, and allows the steam that has accomplished

its work in the cylinder to escape into the exhaust port. This is shown in Fig. 3.

Angular Advance. By angular advance is meant the angle which the eccentric is in advance of the position necessary to bring the valve to its central position when the crank is on the dead center. In other words, in order that the full pressure of the steam may come upon the piston at the beginning of the stroke, the angle between the crank and eccentric is never made 90 degrees, but something greater. The increase above 90 degrees is called the angle of advance.

Valve Travel. The travel of the valve is the total distance that the valve moves in one direction. If the valve is moved directly by the eccentric, it equals practically twice the throw of the eccentric.

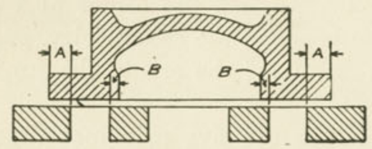


Fig. 5.

LAP.

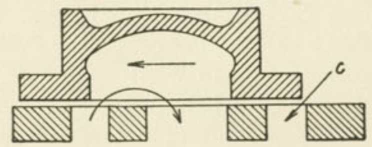


Fig. 6.

LEAD.

Overtravel. Any distance that the valve travels over and above that necessary to fully open the steam port is called overtravel. This is indicated by the distance O T in Fig. 4.

Lap. The lap of a valve is the amount the edges of the valve extend over the ports when the valve is in the center of travel. Lap is used on valves so that the steam may be cut off before the end of the stroke, thus enabling the steam to be used expansively. Lap on the steam side is called steam lap, and lap on the exhaust side is called exhaust lap. Fig. 5 shows a plain D-slide valve in its central position, and A A represents the steam lap and B B represents the exhaust lap. The purpose of steam lap is to allow the steam to be used expansively in the cylinder, and the exhaust lap is used to delay the release of the steam and to hasten compression. If a valve has no steam or outside lap, it would admit steam throughout the whole stroke. Another effect would be a late exhaust, by which is meant that the exhaust would occur at one end of the cylinder at practically the same moment that admission occurred at the other end.

Lead. This is the amount the port is open at the beginning of the stroke. When the engine is on center, the valve is usually moved on its valve stem, or the angle of advance is adjusted until the port just begins to open. This amount of port opening, as shown at C, Fig. 6, is called the lead, and all successful engines must have some little lead. It varies in different engines from 1-32 to 5-16 inches. The higher the speed and the more irregular the work, the more lead will be required for any engine.

Eccentricity. The travel of the valve of most modern engines is caused either by a crank or by means of an eccentric and eccentric strap. This latter arrangement has the same effect as the throw of the crank, and the distance between the center of the shaft and the center of the eccentric is called the eccentricity, and corresponds to what would be the radius of the crank, the function of both being exactly the same.

Functions of a Slide Valve. There are five principal functions which a slide valve must perform in order that the engine may do efficient work: First. It must admit steam into only one end of the cylinder at the same time. Secondly. It must cover the steam ports so as not to permit the passage of live steam through both steam ports at the same time. Thirdly. It must allow the steam to escape from one end of the cylinder before it is admitted at the other end, so as to give the steam that is to be exhausted time to escape before the piston commences the return stroke. Fourthly. It must not permit live steam to enter the exhaust port direct from the steam chest. Fifthly. It must close each steam port on the steam side before it is opened to the exhaust side, so that the expansive force of steam can be utilized.

The Effects of Lap. The use of lap compels the steam in the cylinder to work expansively by cutting off the admission before the end of the stroke. By virtue of the position in which it must be set, it prevents the valve from being in its central position when the engine is at its dead center. The use of exhaust lap prevents the release of expanding steam before the stroke is completed, and closes the exhaust before the exhaust stroke is completed.

Effects of Lead. The effects of lead caused by the moving of the eccentric are as follows: It increases the angular advance; it increases the amount of expansion by causing the steam edge of the valve to close the admission port earlier; it increases the effect of inside lap at one end and decreases it at the other; the clearance volume and port passages are allowed to become filled with live steam, so that full pressure of the steam comes on the piston at the beginning of the stroke; it causes the reciprocating parts to come to rest more easily by the admission of a cushion of live steam before the end of the stroke.

Effect of Changing Dimensions of Valve. Increasing the lap lessens the lead, makes admission later and cut-off earlier.

An increase in the angular advance increases the lead, makes admission and cut-off earlier.

If the eccentricity is increased, steam is admitted earlier and cut-off later, the lead and overtravel being increased.

VALVE GEAR DIAGRAMS.

Valve diagrams show at a glance the movement of the valve for any movement of the piston, and are very useful for giving the various events which take place throughout the stroke. There are various forms of diagrams which are more or less used, but that developed by Dr. Gustav Zeuner is perhaps the most used and the most convenient.

Zeuner Diagram. Since the crank revolves through an angle of 360 degrees each revolution, the travel and position of the crank can be represented by a circle, and since, also, the eccentric center travels in a circle around the center of the shaft, the eccentricity or throw of the valve can be represented by a circle.

Suppose, in Fig. 7, O X represents the position of the crank at dead point, then O Y will represent the position of the crank after the crank has traveled 90 degrees in the direction of the arrow. If it is also assumed that the engine has no angle of advance, the eccentric will be exactly 90 degrees from the dead center, or its center line will occupy the position O E when the crank is at its dead point O X. If, then, on O E as a diameter, a circle be drawn, the circumference will represent the movement of the eccentric or valve when the crank is traveling 180 degrees.

With the diagram as shown in Fig. 7, the engine is represented without lap, so that when the crank is occupying the position O X the valve is in its central position. But just as soon as the crank moves through any angle, as O B, the valve will

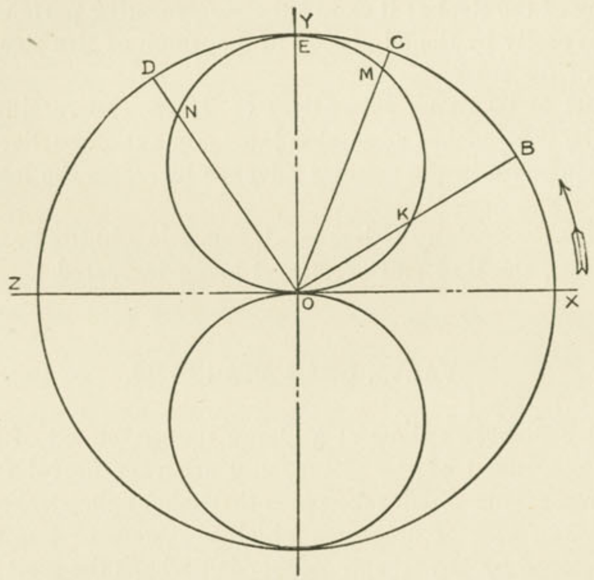


Fig. 7.

Elementary Valve Diagram.

be opened the length of chord of O K. The port will continue to open until the crank reaches the piston O E, at which point the valve will be at one end of its travel. From this point the valve continues to close the port, but does not entirely close it until the end of the stroke, or when the crank has reached O Z. O K, O M, O E and O N represent the different port openings for the different positions of the crank.

Lap and Lead on Valve Diagram. When a valve is provided

with outside lap, and when the port must be opened by an amount of the lead at the commencement of the stroke, the valve can no longer be in its central position when the crank is on dead center. The angle of advance must be greater than 90 degrees, and to represent it on the diagram it is only necessary to revolve the valve circle through the angle A, as shown in Fig. 8. The diagram is then constructed as follows:

Describe the circle with a radius O X equal to the half-throw of the eccentric. From O measure off O B equal to the outside lap and B C equal to the lead. When the crank pin occu-

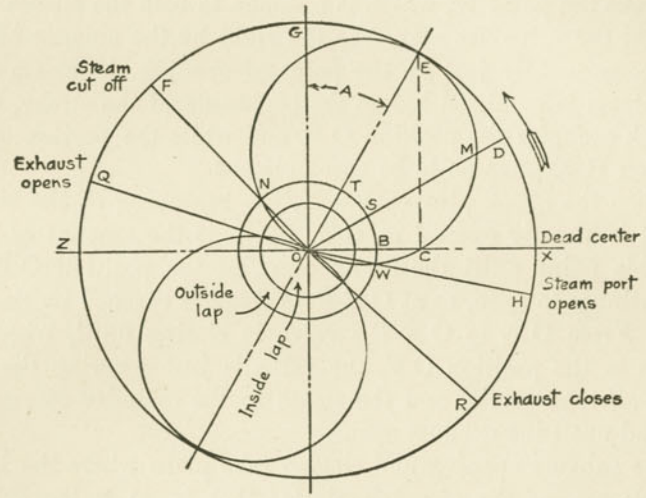


Fig. 8.

Valve Diagram Showing the Functions of a Slide Valve.

pies the dead center the valve has already moved to the right of its central position by the space OB+BC. From C erect a perpendicular C E and join O E. Then O E will be the position occupied by a line joining the center of the eccentric with the center of the crank shaft at the beginning of the stroke. On the line O E as a diameter describe the circle O C E; then, as in Fig. 7, the chords O M, O E, O N represent the distance traveled by the valve from its central position when the crank pin occupies the position corresponding to O D, O E and O F. But these chords no longer represent the extent to which the outer edge has opened the steam port, because before the port is opened at all the valve must have moved its central position by an amount equal to O B. Hence to obtain the port opening for any position of the crank the length O B must be subtracted from the length of the chords O M, O E, etc.

The amount of lap is thus always represented by drawing a circle with O as a center and O B as a radius, and the spaces S M, T E, etc., give the amount of port opening for the respective positions of the crank.

To follow the action of the valve in cutting off and admitting steam, take the point W, which is common to both the circles. At this point the valve has moved to the right by the amount of lap, and is consequently just on the point of opening the steam port. Hence steam is admitted before the beginning of the stroke, when the crank occupies the position O H and while the portion of the revolution H X remains to be accomplished.

When the crank pin reaches X, the beginning of the stroke, the port is already opened at B C, which is the amount of lead. From this point until the crank occupies the position O E the port continues to open, as at O E the valve has reached its limit of travel. From O E to O F the valve is closing until, when the crank is in the position O F, the valve is just covering the port and cut-off takes place, and the steam in the cylinder commences to expand until the exhaust opens.

The exhaust opening and closing take place where the inside lap circle crosses the eccentric circle; that is, at R the exhaust closes and compression takes place until at H, when live steam is admitted. The exhaust valve then remains closed until the crank occupies the position O Q, when it opens.

Therefore, the diagram tells the following story:

Steam is admitted to the cylinder at H before the commencement of the stroke; at dead center X the valve is already opened by an amount equal to B C; at E the valve has reached one end of its travel; at F steam is cut off, consequently admission lasted from H to F; at Q the exhaust opened, so that expansion lasted from F to Q; at R the exhaust closed, and compression begins and continues until fresh steam is admitted at H.

Many problems, otherwise complex, can be easily solved by means of this form of diagram. One of these is as follows: Given the angle of advance, valve travel and cut-off, to find the lap and lead of the valve. The solution is shown in Fig. 9, and the construction of the valve diagram is as follows:

Since the valve travel is known, describe a circle with the radius O A equal to one-half the valve travel, and draw its vertical and horizontal diameters. The angle of advance being given, lay off the angle B O E, marked D, equal to it. Then O E will

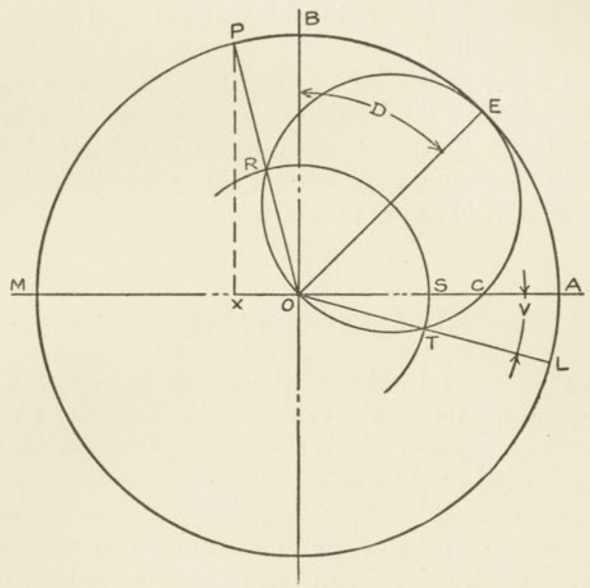


Fig. 9.

Method of Finding Lap and Lead.

represent the position occupied by a line joining the center of the eccentric with the center of the crank shaft. On the line O E as a diameter describe a circle. Then any chord drawn from O to the circumference of the circle will represent the space traveled by the valve when the crank is in that position; for instance, when the crank would be on its dead center, as represented by line O A, then the distance O C will represent the amount the valve has moved from its central position.

The cut-off being given, lay off on the line A M from A the proportion of the stroke that cut-off is to take place, as at X; draw P X perpendicular to A M and draw P O. P O represents the position of the crank at cut-off, and the distance O R represents the steam lap. With O R as a radius and O as a center, draw the steam lap circle which crosses O A at S and the eccentric circle at T. S C represents the amount the port should be opened at the beginning of the stroke, and hence is the amount of lead, and the angle A O L, marked V, is the angle of lead. Therefore, by measuring O R and S C the amount of lap and lead can be easily obtained.

As all problems bearing on valve gearing involve the relation of such variables as the inside and outside lap, the angle of advance, the throw of the eccentric, the admission and cut-off of steam, and the opening and closing of the exhaust, a study of the above diagram will be most profitable.

BALANCED VALVES.

The purpose of the balanced valve is to remove the steam pressure from the top of the valve, so that the wear on the valve seat will not be so great. This subject of relieving slide valve engines of a portion or the whole of the excessive steam pressure to which the valve is subjected, while performing its customary function, has resulted in the design of a number of devices, many of which have failed, however, in the purpose for which they were intended, principally on account of the fact that they do not take into consideration the irregularity of the wear on the valve seat, which, if not provided for, will cause leakage of steam and develop more trouble than that which it is intended to remedy.

The Wilson Balanced Valve. One type of valve which is made for the purpose of relieving the pressure on the valve is shown in Figs. 10 and 11, which represent a top view and cross-section of the Wilson high pressure slide valve. The valve has two faces, and is similar to the "gridiron" valve, one face acting against the valve seat and the other against the balanced plate. The face of the balance plate is an exact duplicate of the cylinder valve seat,

and forms a second valve seat, against which the valve operates in unison. The back or opposite side of the balance plate contains one large or main cone, C, and two small, or port cones, P, on the interior of the main cone, on which the packing rings are placed. This arrangement forms the balancing feature of the valve, the upper face of the packing rings forming joints against the pressure plate. Two grooves are cut in the face of the pressure plate, which are in line with the corresponding grooves in the balance

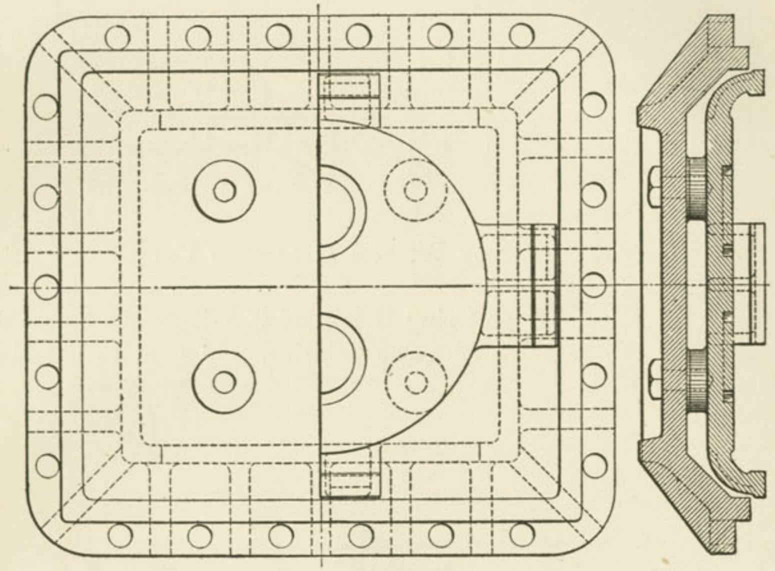


Fig. 10.

Top View of Wilson Balanced Valve.

plate. Into them two centering rings, R, are placed. Under normal conditions these rings hold the balance plate in alignment with the valve seat. The balanced area of the valve is automatically changed, so as to correspond with the changed conditions of the valve on its seat at different points in its travel. In applying this valve to the engine, it is important that the face of the balance plate, or upper valve seat, shall be in alignment with the cylinder seat, in order to secure simultaneous action of the valve at both faces. Direct communication from one cylinder port to the other is always maintained by reason of the ports A and E

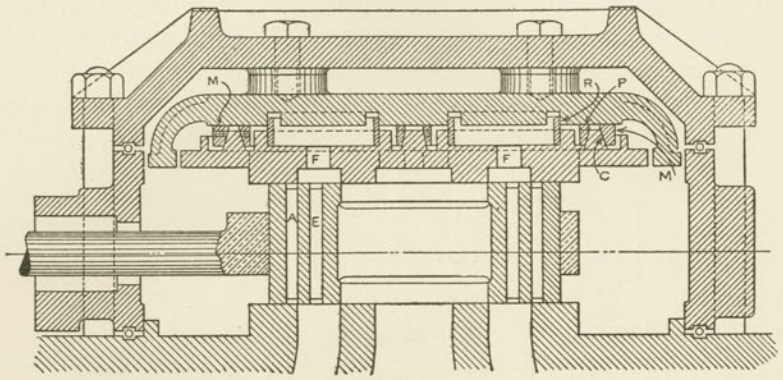


Fig. 11.

Cross-section of Wilson Balanced Valve.

through the valve. A port ring M is used to balance the pressure in the port of the balanced valve, which would tend to lift the plate off the seat.

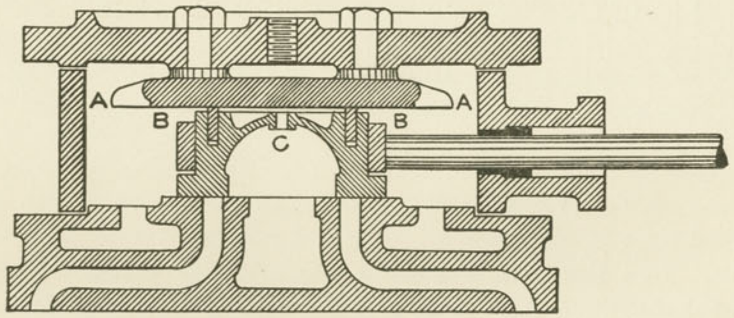


Fig. 12.

The Richardson Balanced Valve.

The Richardson Balanced Valve. This type of balanced slide valve is shown in Fig. 12. The balanced plate A A is bolted to the cover of the steam chest, or may be cast with it. The packing

strips B B prevent the steam from entering the rectangular space enclosed by them, and a small hole, C, communicating with the exhaust cavity in the valve, relieves the space above the valve from any accumulation of pressure. There are four packing strips of cast iron placed in grooves cut in the top of the valve. Beneath each packing strip there is a light elliptic spring, which holds the strips in position. These different sections maintain a steam-tight contact by a direct steam pressure with the balance plate.

The Allen Balanced Valve. The Allen valve is designed to partly prevent the wire-drawing of the steam when high speeds are maintained with early cut-offs. As shown in Fig. 13, an addi-

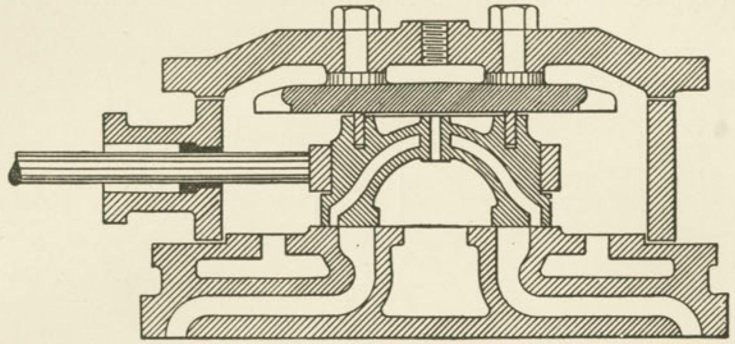


Fig. 13.

The Allen Balanced Valve.

tional passage for the inlet of steam is furnished. It will be noticed that when the steam port is opened one-half inch in the ordinary manner the port of the cored passage is also opened a like extent on the other side of the valve. Consequently the effective area of the steam port is doubled, and is thus equivalent to a single port with a one-inch port opening. To secure the best results from the use of the Allen balance valve, its ports and bridges should exceed the full travel of the valve by at least one-eighth of an inch, and the radius of the link should always be as long as permissible, so as to avoid excessive leads when cutting off early in the stroke.

PISTON VALVES.

The piston valve, which has come into such extensive use for all classes of locomotives, had its first extensive use in high pressure cylinders of cross compound engines because of the difficulty experienced in balancing large slide valves when higher pressure began to be used. In the earlier types these valves were of the outside admission type, because the low pressure slide valve was also necessarily of that type, and it was considered desirable to maintain the valve gears the same for both sides of the engine. With the introduction of the direct valve motion, the inside admission type of piston valve began to be used. The earlier piston

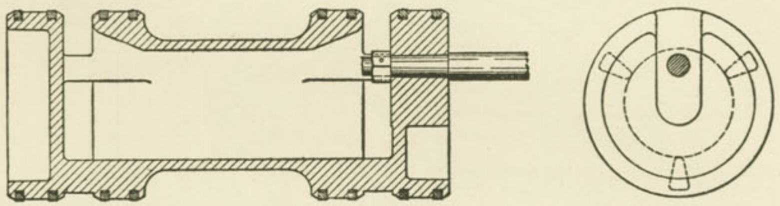


Fig. 14.

SOLID TYPE OF PISTON VALVE.

valves were of solid one-piece construction, as shown in Fig. 14; but, on account of having to snap the piston rings over the solid heads, it was found that this practice always stretched the ring and caused a poor fit. For this reason the built-up valve, which enables the piston ring to be slipped into place without distortion, is now used to a large extent.

Piston Valve Bushings. Piston valve bushings ordinarily have from 7 to 9 bridges, as shown in Fig. 15, the one at the bottom being wider than the others beause of the joint in the packing ring at this point. As these bridges obstruct the flow of steam, the fewer there are the better. If the valve did not require packing rings, there would be no need for bridges. To overcome this difficulty, solid valves have been used which ran in bushings which

could contract or expand; but they have all gone out of use, the nearest thing to the solid piston valve in general use being the "American" piston valve.

The American Semi-plug Piston Valve. This valve is called

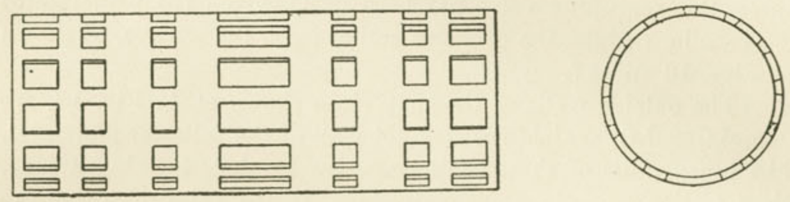


Fig. 15.

PISTON VALVE BUSHING.

semi-plug because when the throttle is closed it is a snap-ring valve; that is, the packing rings are expansible and fit themselves to the valve chamber, but when the throttle is opened the steam is admitted to the chest to enter the space below the rings, and the action of this pressure is to lock the snap rings in a fixed diameter, mak-

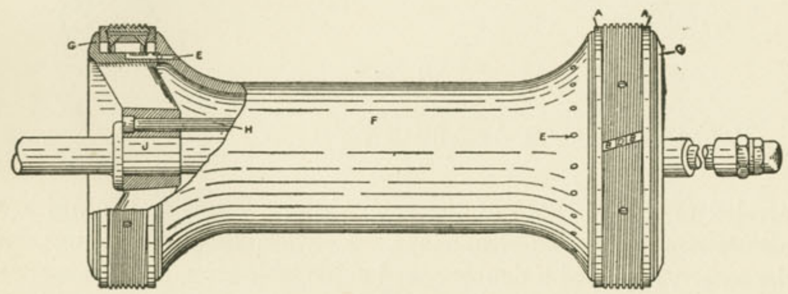


Fig. 16.

AMERICAN SEMI-PLUG PISTON VALVE.

ing practically a plug of it during the time the pressure remains on. This is all-important in a piston valve, for to secure proper service it is necessary to maintain true cages in order to maintain steam-tight valves. Steam-tight valves cannot be secured without proper design and construction of rings to begin with, and the absolute regulation of their frictional contact against the cage to prevent wear of the cages while the valve is working at short cut-off. In addition to this, it is absolutely necessary to prevent lateral wear. In order to accomplish all of these necessary features, this semi-plug valve has been designed on the principle of leverage by wedges, the pressure acting upon the wedges, as shown in Figs. 16 and 17.

The outside walls of the snap rings shown at A, Fig. 17, are straight, and fit against the straight wall of the follower and spool. The inner walls of these snap rings are beveled, forming a cone. Next to the snap rings are wall rings, B, the sides of which are

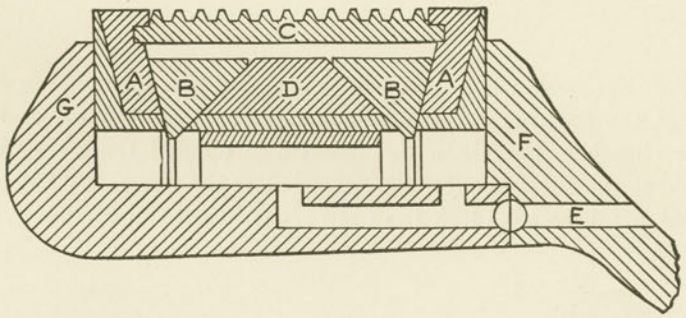


Fig. 17.

Packing Used on American Semi-plug Piston Valve.

beveled to fit the cones of the snap rings. These wall rings are uncut, non-expansible steel rings. Between these wall rings, in the center, is placed a double-coned expansible ring, called a wedge ring, D, and which, with the wide ring, C, interlocked into each snap ring forms the complete packing. The wide ring performs the functions of carrying the snap rings across ports while drifting, and keeping the snap rings parallel with each other.

The operation of the valve is as follows: Wedge ring, D, being under tension, its tendency is to crowd the two solid wall rings laterally against the cone sides of the snap rings, A. This prevents lateral wear of all rings. The degree of angle on the

cones is much greater on the double-tapered wedge ring than on the snap rings. These angles are so calculated that, while the pressure is underneath all the rings, the leverage of the double-tapered wedge ring, crowding the solid wall rings against the cones of the snap rings, is just sufficient to prevent the snap rings from further expansion, but not sufficient to reduce the snap rings in diameter. The frictional contact of the snap rings against the valve chamber depends entirely upon these angles, and it can, therefore, be regulated to any desired degree. Following the action of this valve when steam is admitted to the steam chest, it passes through the small holes around the spool, and finds an outlet,

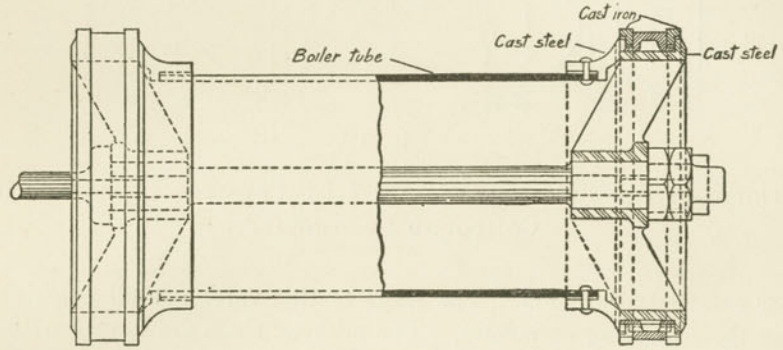


Fig. 18.

Piston Valve Used on the Cole Balanced Compound Locomotive.

first, under the first snap ring, and, second, under the central wedge ring. The velocity of steam from these holes against the first snap ring insures its fitting the valve chamber, and the action against the wedge ring is to place it in position for the pressure to lock up the rings. The packing consists of the combination of rings, which are free to move up and down on the spool so that the rings may fit the cage perfectly correct, regardless of any variation in the position of the spool. As it is disastrous to the valve cage to allow the spool to ride on it, as it wears the cage out of true, and, therefore, destroys the perfection of valve service, no provisions are made for carrying the spool on the rings, and the spool must, therefore, be carried on the valve rod. This is one feature essential in using this valve.

The valves are made for internal and external admission, and have been made for both, that is, reversible, in which case the valve is used as a reversing gear by changing the steam to internal

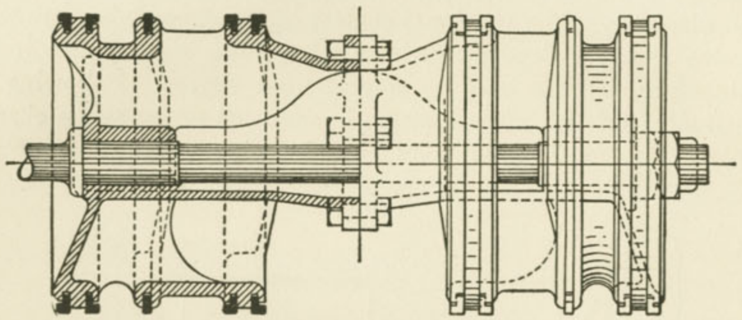


Fig. 19.

DOUBLE-PORTED VALVE USED ON LOW PRESSURE CYLINDERS OF COMPOUND LOCOMOTIVES.

or external admission. The rings of this valve are all machined in their working diameters. The packing rings are lapped with a solid steel joint-plate, the side of which is beveled, bringing it to a sharp edge at the periphery of the ring, thereby avoiding any notches in the seam or exhaust lines of the valve.

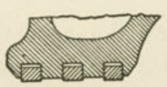


Fig. 20.

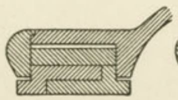


Fig. 21.

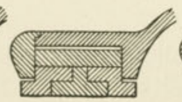


Fig. 22.

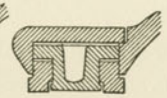


Fig. 23.

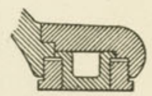


Fig. 24.

TYPES OF PISTON VALVE PACKING.

Two types of piston valve which are used on compound engines are shown in Figs. 18 and 19. Fig. 18 represents a piston valve which is used on both the high and low pressure cylinders of the Cole balanced compound engine. In this valve the body or spool consists of seamless steel tubing, with light case steel ends riveted

on. Fig. 19 represents a double-ported valve used on the low pressure cylinder of a cross compound engine for passenger service. This arrangement gives a large port opening necessary for high speed work and large cylinders.

Piston Valve Packing. The earlier types of piston packings are shown in Figs. 20, 21 and 22, that shown in Fig. 22 having been used quite successfully with low steam pressures; but as pressures increased the types shown in Figs. 23 and 24 came into general use. The L-shaped piston packing shown in Fig. 24 is practically standard throughout the country to-day. The packing ring is L-shaped, the T-ring composing the middle of the face being a non-expansive ring.

Packing rings are turned from 1-16 to 3-32 inches larger than the bore, according to the size of the valve; then from 1-8 to 3-16 inches is cut out, the ring clamped together in a jig and turned to nominal size. This gives a ring which will bear all around the bushing and wear equally.

Diameter of Piston Valves. The diameters of piston valves for different bores are given in the accompanying table. The table also shows the net length of the port, with the bridges deducted, for each diameter and the corresponding length of the slide valve port in common use.

Diameter of Cylinder	Diameter of Valve	Net Length of Piston Valve Port	Length of Slide Valve Port
17	10	25	16
18	11	26½	16
19	11	26½	18
20	12	30½	18
21	12	30½	18
22	12	30½	20
23	14	34	20

Lubrication of Piston Valves. There are two methods used for oiling inside admission piston valves. One method admits the oil to the center of the steam passage in the saddle, while the second involves the use of branch pipes, which deliver the oil at the top of the valve itself through a hole in each bushing. The

41

latter method is considered more certain and economical, provided that the oil holes are not spaced so widely apart that the steam ring passes them, thereby making it dependent upon the exhaust ring to keep the oil out of the exhaust passage, because the exhaust rings are more or less unreliable, and as a result the oil will be blown past them and is lost. When this method is used, the oil studs should be so spaced that the valve will just wipe off the drop at the shortest stroke.

Material Used for Bushings and Packing Rings. The following specifications for castings used for bushings and packing rings have been adopted by the American Master Mechanics' Association as follows:

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

Advantages and Disadvantages of the Piston Valve. The advantages of the piston valve are perfect balance; a simple and cheap cylinder casting; a wearing face separate from the cylinder casting, which can be cheaply renewed; ports in cylinders may be made straight and direct; its adaptability to any design of valve gear. Generally speaking, its tightness is conceded to be about equal to that of a good slide valve.

Among the disadvantages of the piston valve may be mentioned that the size of valve required for a given diameter cylinder is quite large, owing to the existence of the bridges in the valve ports; in some types the clearance required is large; valves with inside admission have a tendency to jump at the moment exhaust takes place; the collapse of the exhaust ring just prior to release, which causes increased wear on the ring and its faces; its inability to relieve excess pressure in the cylinder port by lifting, after the manner of the slide valve. As regards the disadvantage due to cylinder clearance, with the proper design of valve, the clearance can usually be kept between 6 and 8 per cent, so that

this is not considered a serious objection. As regards the valve jumping at exhaust, it is worse with a valve follower having a considerable overhang than with one having a long bevel. Valves which have a large diameter of body, forming a free communica-

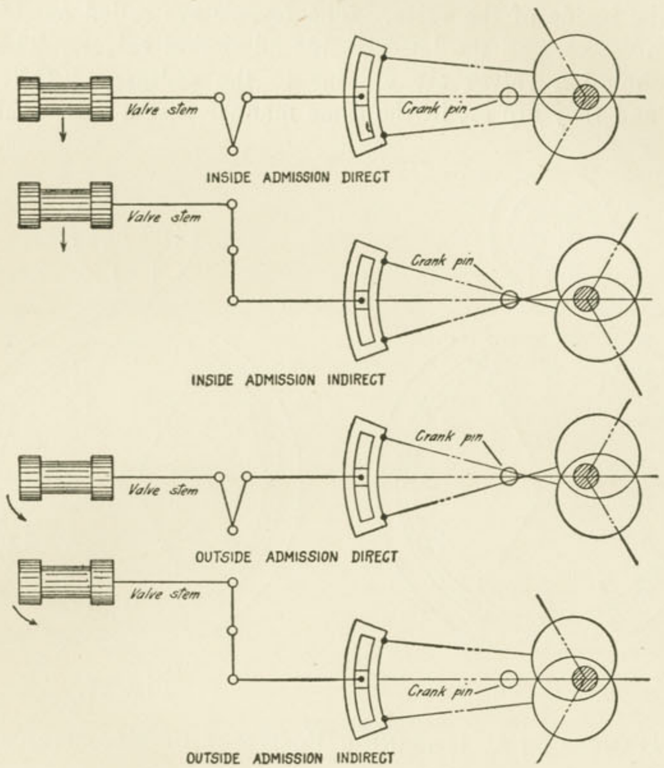


Fig. 25.

DIFFERENT TYPES OF VALVE MOTION.

tion between the opposite ends, do not exhibit this fault to such a degree, as the exhaust pressure is somewhat equalized.

The inability of the piston valve to relieve the excess pressure is its greatest disadvantage. When the piston valve is used, some sort of cylinder relief valve is necessary. For this purpose, the ordinary spring top valve is used with success, as well as various types of by-pass valves, the objection to the latter, however, being that they increase the cylinder clearance.

Setting Piston Valves. There are two classes of piston valves in use: those which admit steam to the cylinders from their outer edges and those which admit steam from the central portion, or from the inside of the valve. The former are called outside admission valves, and the latter inside admission valves. The outside admission valves are similar to the ordinary "D" slide valve, and they are set in the same manner that a "D" valve is

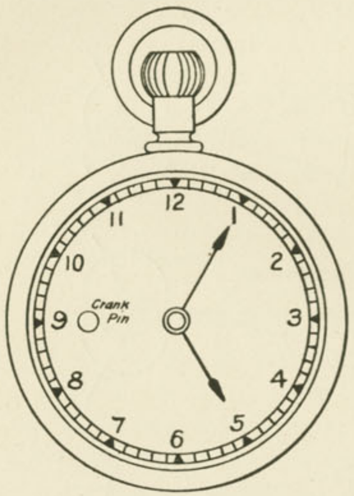


Fig. 26.

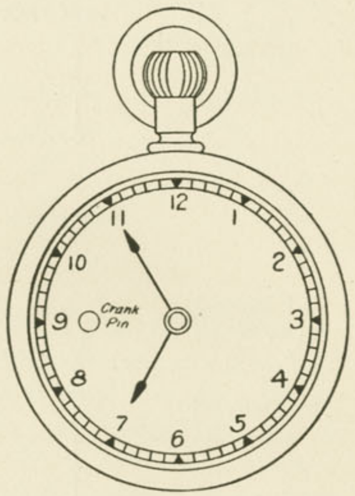


Fig. 27.

METHODS OF DETERMINING POSITIONS OF ECCENTRICS.

set. The setting of any valve is modified by the method of connecting it with the links and the eccentric rods. There are two ways in which this connection may be made. The first is with an ordinary rocker, pivoted in the center with one arm up and the other down. This rocker transforms a forward movement of the eccentric rod into a backward movement of the valve, and is therefore called an indirect motion. The second is where the valve stem and transmission bar (which terminates in the link block) are attached to rockers, the arms of which are both above

or below the pivot point. This is called a direct motion because the movement of the eccentric produces a like movement of the valve. There are therefore four combinations to be considered when setting a piston valve. These are shown in Fig. 25.

Before setting a piston valve it is necessary to know which kind of motion is used and also the kind of valve. When the valve is of the outside direct type, if the crank pin be represented by the figure 9 on the dial of a clock shown in Fig. 26, and the center lines of the eccentrics by the hands, the latter will stand approximately at five minutes past five. This is called the afternoon, or P. M., style of setting. Since the outside admission valve resembles the "D" slide valve, the arrangement of eccentrics conforms to stationary practice. With the inside direct valve the eccentrics lie on the same side as the crank pin, and their lines make what is called a morning, or A. M., setting. In this case, with the crank at 9 on the dial, the lines through the eccentrics will mark approximately twenty-five minutes to eleven, as shown in Fig. 27. The outside admission valves with indirect eccentrics are also set with the center lines to correspond to the hands when set at twenty-five minutes to eleven, while the inside admission indirect eccentrics are set the same as the outside direct, or five minutes past five, as shown in Fig. 26. The inside direct and outside indirect are therefore set as shown in Fig. 27, and the outside direct and inside indirect valve motions have their eccentrics set as shown in Fig. 26.

VALVE MOTIONS.

There are various kinds of valve motions which have been invented for the purpose of properly distributing the steam to the steam cylinder of an engine. The principal ones which have been used on locomotives are the Stephenson link motion, the Gooch link motion, the Joy valve gear, the Allan link motion, and the Walschaert link motion. All of these link motions have been devised for the purpose of not only distributing steam to the engine properly, but also to reverse the engine and give any speed of the locomotive required. Of all the various types of valve motions which have been designed for this purpose, there are only two which have survived in this country, and they are the Stephenson link motion and the Walschaert link motion. Up until a few years ago, the Stephenson link was used almost exclusively in this country, but within the past few years the Walschaert valve motion has come into extensive use, and is crowding the Stephenson motion in maintaining its position as the leading type of American locomotive valve gear. The Gooch link motion and Joy valve motion have been used principally in Europe, and the Allan link motion, although it balances the valve parts very evenly, has fallen into disuse, so that in the discussion of types of valve gears used in American locomotive practice the Stephenson and Walschaert are the principal ones that need be extensively considered.

THE STEPHENSON VALVE MOTION.

The Stephenson valve motion consists of two eccentrics, two eccentric straps, two eccentric rods, a link, link block, hanger, rocker arm, rocker shaft, tumbling shaft, reversing rod, reversing rod arm and valve stem. The arrangement of these parts is shown clearly in Fig. 28, and each valve has the same arrangement for giving it its proper motion.

The movement of the valve, which derives its motion from two fixed eccentrics by means of a link, is very complex. These complications arise from the irregularity of motion which is introduced by the angularity of the eccentric rods, the movement of the link, and the rising and falling of the link, which is commonly called the slip. The angularity of the main rod also introduces irregularities into the motion of the piston which affects the points of cut-off and exhaust closure.

Arrangement of Parts. Referring again to Fig. 28, it will be seen that the eccentrics are keyed to the main shaft, their centers being indicated by A and B respectively. The eccentric straps are attached to the eccentric blades, and these in turn are bolted to the link near both the bottom and top, the forward eccentric blades being attached to the top of the link, and the backing eccentric being attached to the bottom of the link. The slide valve

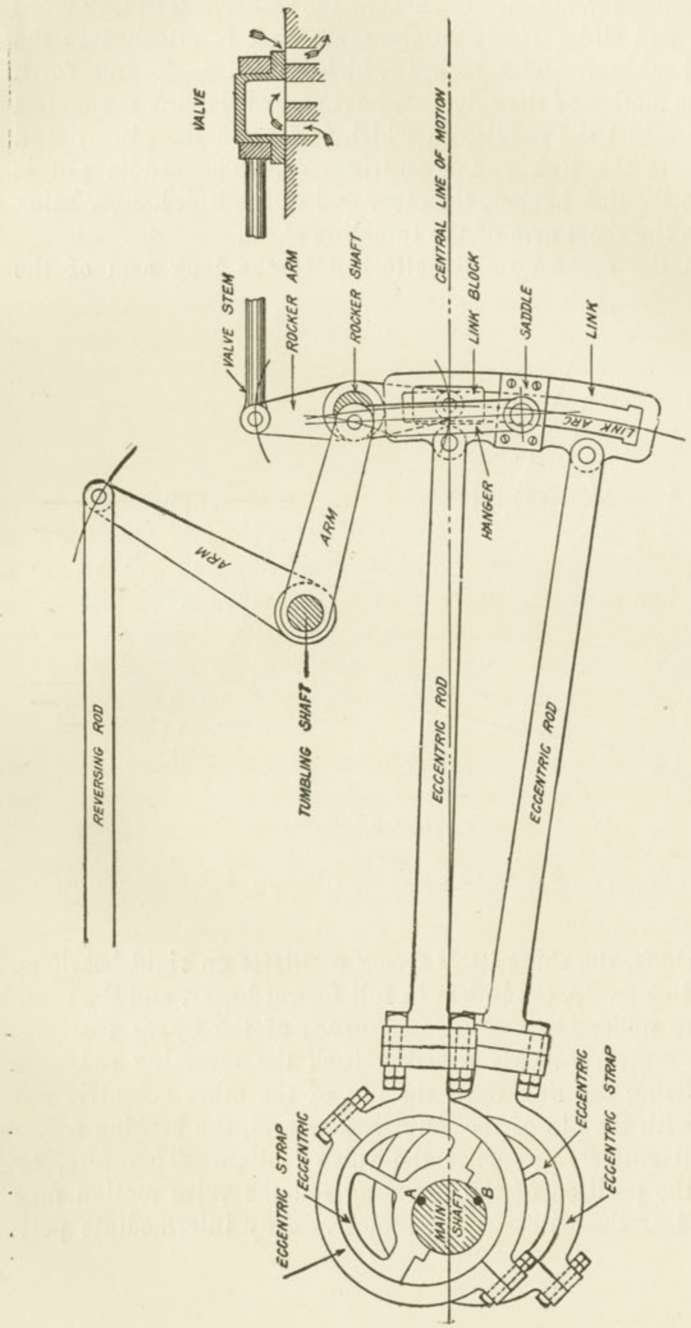


Fig. 28.
Stephenson Link Motion.

is attached by its stem to the top arm of the rocker. The link block which fits and slides freely in the main link is attached to the lower rocker arm. The rocker which moves back and forth reverses the motion of the valve. The center of the link is spanned by a plate called the saddle, on which is formed the pin or stud that supports the link and eccentric rods. The saddle pin is attached to the link hanger, the other end of the link hanger being attached to the short arm of the tumbling shaft.

When the reverse rod is attached to the long arm of the

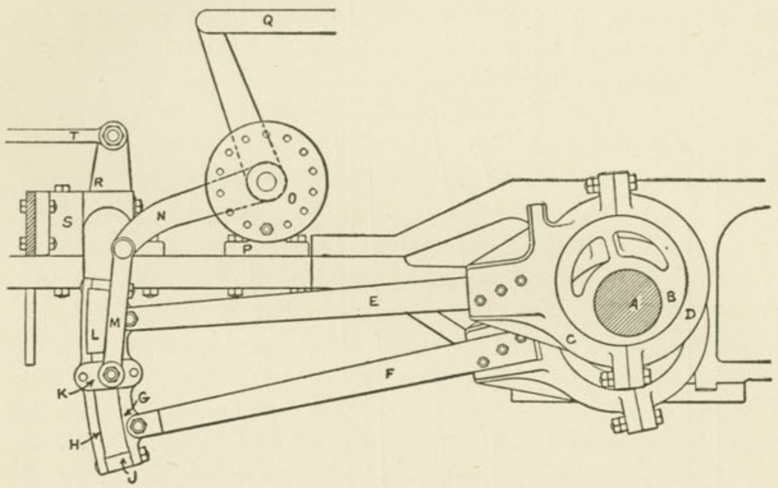


Fig. 29.

Arrangement of Parts of Stephenson Link Motion.

tumbling shaft, the shaft itself freely oscillates on rigid bearings. As shown in Fig. 28, the link is in full forward gear, and the valve is therefore under the complete influence of the upper eccentric rod and eccentric A. By drawing back the reversing rod, and thereby raising the link until the pin of the other eccentric rod is in line with the pin of the lower rocker arm, the backing eccentric B will entirely influence the valve motion. Therefore, by changing the position of the reversing rod the valve motion may be reversed at the will of the engineer. Any intermediate position of the length causes the valve to be under the influence of both eccentrics, and since their motions oppose each other the travel is reduced until when the block is in the center position the valve has practically no motion at all.

The arrangement of parts of the Stephenson link, as manufactured by the Baldwin Locomotive Works, is shown in Fig. 29. The axle is shown at A; the eccentric at B; the front half of the eccentric strap at C; the back at D; the forward motion eccentric rod at E; the backing eccentric rod at F; the reverse link at G and H; the distance piece at I; the saddle at J; sliding block at K; link lifter at L; reverse shaft at M; counterbalance spring at N; reverse shaft bearing at O; reverse lever rod at P; rocker shaft at Q; rocker shaft box at R; and valve rod at S.

Peculiarities of the Stephenson Link Motion. The Stephenson link motion has certain peculiarities. If the valve have neither lap or lead, and the eccentrics were connected 180 degrees apart, the valve would have no motion when the block is in the middle of the link. The angle between the eccentrics is not 180 degrees, on account of the lap and lead, so that when the block is in its central position under these conditions the valve is moved, but usually not sufficient to open the port. With the block at intermediate points above or below the center, the travel of the valve is less than the full throw of the eccentric, so that earlier cut-off and greater expansion will be obtained by this diminished throw, and yet without seriously distorting the exhaust closure, since the angular advance of the eccentric is not changed.

The principal objection to the Stephenson link, as far as the steam distribution is concerned, has been its variation of lead at different points of cut-off, although it is of no great disadvantage in locomotive practice to have the compression increase with early cut-off.

The increase in lead is caused by bringing the reverse lever nearer the center of the quadrant, or, as it is usually called, "hooking her back," in order to cause cut-off to take place earlier, the increase in lead being due to the radius of the link.

Radius of the Link. Providing the rocker arm has no backset, the correct radius of the link is the distance on a horizontal line from the center of the main driving shaft, which carries the eccentrics to the center of the rocker shaft. If the rocker has any back-set, subtract the amount of back-set from this length.

Travel of the Valve. The travel of the valve cannot be less than twice the sum of the width of the steam port and lap. When the rocker arms are of equal length, the throw of the eccentric is equal to the travel of the valve. The travel, approximately correct, can be found by adding together the width of one steam port, the outside lap, one and one-half the width of the bridge, and double the entire amount.

The travel of the valve is twice the sum of the steam port, plus the lap, plus any amount of overtravel which the valve may have. For instance, if the width of the port is $1\frac{1}{2}$ inches, the lap $\frac{3}{4}$ of an inch, and the overtravel $\frac{1}{4}$ inch, the travel of the valve is five inches.

Throw of the Eccentric. The throw of the eccentric may be determined by finding the distance between the center of the shaft on which it is mounted and the center of the eccentric. It can also be obtained as follows: Measure the greatest distance from the shaft to the outside of the eccentric, then measure the least distance to the outside of the eccentric, the difference between the greatest and the least distance will be its throw. If both arms of the rocker are of the same length, the throw of the eccentric should be the same as the travel of the valve. If the rocker arms are of unequal length, the top arm being the longest, then to find the throw multiply the length of the lower arm by the travel of the valve, and divide the result by the length of the top arm.

Length of Eccentric Blades. The length of the eccentric blades is the distance from the center of the eccentric strap to the center of the link pin hole. If the rocker has no back-set, the correct length of an eccentric blade should equal the exact distance on a horizontal line between the distance of the main driving shaft and the center of the rocker box, less the distance from the link arc to the center of the link pin-hole. If the rocker arm is back-set, subtract the amount of back-set from its length. To find the length of an eccentric blade of a given engine, see that the shoes are properly tightened, and place a straight-edge across the two main shoes. Drop a plumb line through the center of the rocker box, measure the distance from the straight-edge of the line, and add to this length one-half the thickness of the driving-box, then subtract from this sum the distance from the center of the link block to the center of the link block hole, and the difference will be the length of the eccentric blade. Should there be any back-set of the lower rocker arm, this should also be subtracted.

Valve and Stem Yoke. Since most modern locomotives have their cylinders and valves parallel to the wheel centers, the length of the valve stem yoke can be obtained by dropping a plumb line through the center of the rocker shaft and measuring the distance from this line to the center of the exhaust port. This will give the correct length for the valve stem from the center of the yoke to the center of the rocker pin-hole. If the valve seat is inclined, the top arm of the rocker should be set at right angles with the valve seat. This may be done by placing a long straight-edge on the valve seat and using a two-foot square at the rocker and setting the center line of the rocker arm true with the square and measuring the distance from the center of the rocker arm to the center of the exhaust port. This distance is the length of the valve stem and yoke.

Link Hanger. When finding the length of the link hanger, the top arms of both the tumbling shaft and the rocker should be perpendicular or in their correct positions, then from the center of the lower rocker arm and on a horizontal line with it lay off the back-set of the saddle stud, and from this point find the distance to the center of the short arm of the tumbling shaft. This will give the correct length of the hanger.

Length of Reach Rod. To find the length of the reach rod, first place the reverse lever and top arm of the tumbling shaft in their proper positions, then plumb the reverse lever and find the exact distance between the center of the hole in the reverse lever and the center of the hole in the tumbling shaft arm. This will give the correct length from center to center.

Back-set of Rocker Arm. As the top and bottom arms of the rocker are entirely independent of each other as regards the amount of back-set which they have, either of them may have more or less back-set than the other. The top arm should be at right angles to the valve seat and the bottom arm at right angles to the center line of motion, in which case each arm will travel an equal distance from its central position. The method of finding the back-set of a rocker arm is shown in Fig. 30. Draw a horizontal line, A B, parallel with the line centers, and locate the point H the correct distance from the main shaft and the right distance above the line, A B. This point indicates the center of the rocker shaft. Now erect the perpendicular, C D, at right angles to the valve seat, with a pair of dividers set to the length of each rocker arm, and describe arcs from the point H, equal in length to each rocker arm, then draw the line E F through the center of the shaft which intersects the lower arc and represents the

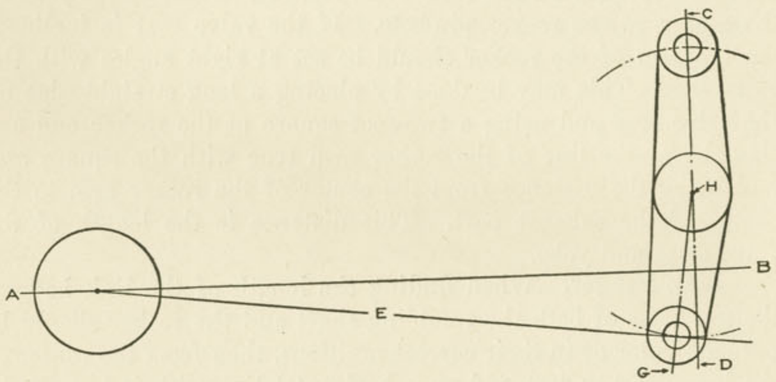


Fig. 30.

How to Find Back-set of Rocker-arm.

length of the lower rocker arm. Through the center H erect the line G H at right angles to the line E F, the distance between the line C D and the line G H of the lower arc is the required back-set, the line E F being the center line of motion. With this method the length of the eccentric rods and rocker arms must, of course, be known. When the throw of the eccentric and the travel of the valve are known, the length of each rocker arm can readily be determined, provided the position of the rocker box is known.

Place a straight-edge across the top of the frames and measure the distance to the center of the rocker box, then measure the distance to the center of the stuffing box. If the rocker box is

above the frame, the difference between two measurements will indicate the length of the top arm, and if the rocker box is below the top of the frame, measure the distance it is below the frame, add these two measurements together, and add about one-eighth of an inch to provide for the circular motion imparted to the valve stem. The result will be the length of the rocker arm. If both arms are of equal length, the movement of the valve will be the same as the movement of the eccentric; but if the valves are of different lengths, they must be proportioned according to the throw of the eccentric and the valve motion required. If the throw and travel and length of the bottom arm are known, the length of the top arm can be obtained by multiplying the length of the lower arm by the travel of the valve, and dividing the result by the throw of the eccentric.

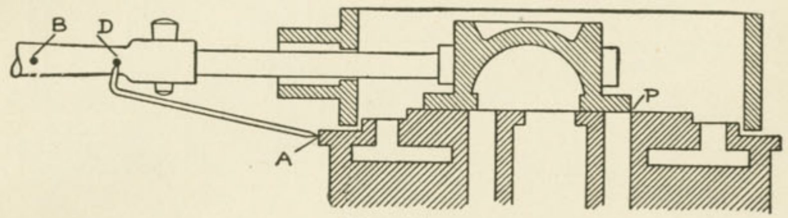


Fig. 31.

Method of Marking Port Opening.

Setting the Valves. The correct setting of the valves of a locomotive means that the adjustment of the positions of the eccentric on the driving axle and the lengths of the eccentric blades, valve rods and valve stems should be such that each valve will give the required distribution of steam to the piston that it has to serve. Before beginning to set the valve, all parts of the valve gear should be properly adjusted, so that there is no lost motion, the go-ahead eccentric rod being attached to the top of the link and the back-up eccentric to the bottom end of the link. A large majority of locomotives are equipped with the indirect motion, in which the eccentric that controls the valve always follows the crank pin; that is, when the pin is on the forward center, for instance, the body of the go-ahead eccentric will be above the axle and that of the backing eccentric will be below. Both eccentrics will be advanced toward the crank pin the amount of the angular advance.

The eccentrics should be placed in their approximate positions, and the set-screws slightly tightened. Having done this, the ports should next be properly located on the valve rod. To do this the steam chest covers must be removed, the valve rods adjusted for lost motion, and the stuffing box gland should be in its proper position.

For convenience in setting the valves, the location of the valve should be marked on the valve rod by means of a tram. As shown at P in Fig. 31, the forward port is just about to open. When the valve is in this position, mark the corresponding point on the valve rod by means of a tram, which has its fixed point, A, on

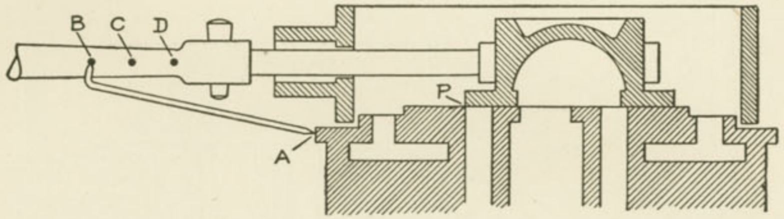


Fig. 32.

METHOD OF FINDING CENTRAL POSITION OF VALVE.

the cylinder, the point being indicated by D on the valve rod. Now move the valve ahead so that back port and back edge of the valve come in line, as shown in Fig. 32. Now take the same tram, and from the same point A scribe the line B on the valve rod. The center D represents the forward port mark and center B the back port mark. The central position of the valve should also be found by dividing the distance between B and D, as shown at C, Fig. 32. The points D and B represent the points of admission and cut-off, and the distance from B to C and D to C represents the lap of the valve.

If the valve should have neither inside lap nor inside clearance, the point C will represent the points of both release and compression. If the valve has inside lap or inside clearance, these

points may be marked on the valve stem by laying off from the point C a distance equal to the inside lap and inside clearance. These points should be marked so that their significance will always be known.

Having found the various points on the valve stem to correspond to the different valve events throughout the stroke, the dead centers of each crank pin should be accurately found. It is very

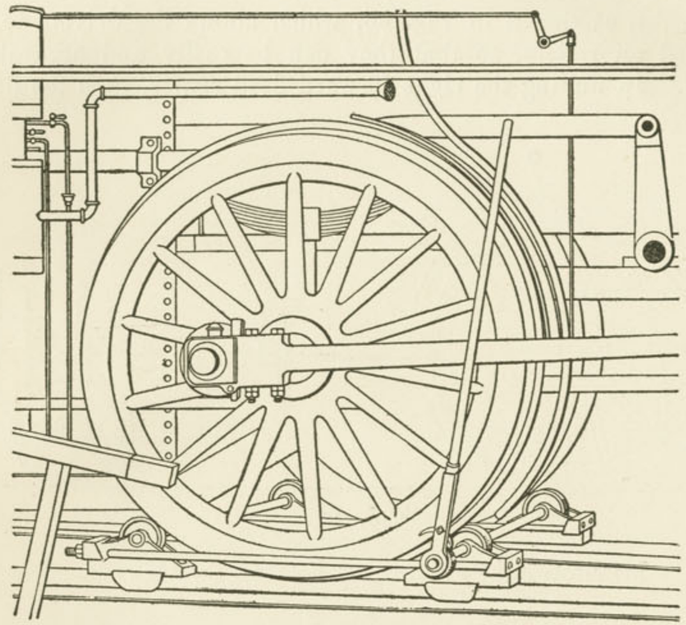


Fig. 33.

ARRANGEMENT FOR MOVING DRIVERS.

important in valve setting that these be found, because while the crosshead moves very little when the crank is approaching the dead center, the valve is moving at nearly its greatest speed, so that a slight error in locating the center will considerably affect the proper setting of the valve.

The dead center of an engine occurs when the center of the crosshead pin, the center of the crank pin and the center of the driving axle are exactly in line. As each crank pin must pass two dead centers in each revolution, there are therefore four dead centers in each revolution which should be located and marked. These are, first, the right forward dead center; second, the right back dead center; third, the left forward center; and fourth, the left back center.

In finding the dead centers it is necessary to move the driving wheels, so that in many shops it is usual to find some sort of an equipment, as shown in Fig. 33, which allows the drivers to be mounted on rollers, so that they can be easily and accurately turned. In finding the right forward dead center, turn the driv-

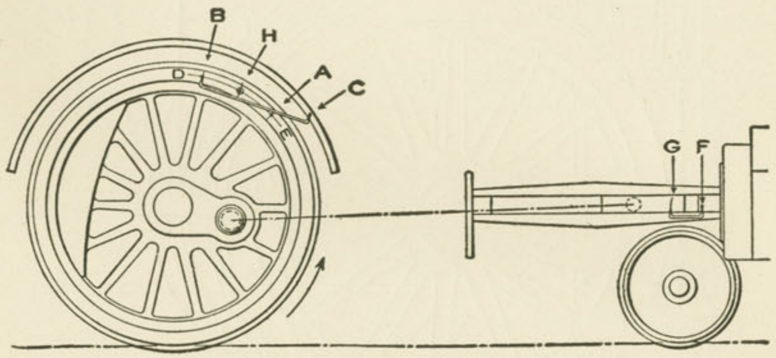


Fig. 34.

METHOD OF PUTTING AN ENGINE ON CENTER.

ing wheels forward until the crosshead is within an inch of the forward end of the stroke, as shown in Fig. 34. Make a mark upon the frame as at C, and with a wheel tram set in center C, describe an arc A on the tire of the wheel. Make a fixed mark upon the crosshead guide as at F, and with a crosshead tram draw the arc G upon the crosshead. Now turn the wheel ahead and past its center until the mark G comes opposite the point of the tram. Then with the wheel tram set in center C scribe an arc B on the tire. Next bisect the distance between A and B, and mark the point H as representing the center point. Having found the center point H, throw the reverse lever into the extreme back notch, so as to take

up all the lost motion in the valve gear, and bring the engine back until the center H comes exactly under the point of the tram. The engine is now on the right forward dead center, and a vertical line should be drawn on the guides to exactly correspond with the front end of the crosshead.

A similar method is shown in Fig. 35. Make a center-punch mark at any convenient place on the wheel cover, say at E. Then turn the wheels ahead until the crosshead is at one-quarter of an inch from the end of its travel. With one point of a tram placed in the point E scribe an arc F on the edge of the tire, and before moving the wheels, with the same tram, and with the point J on

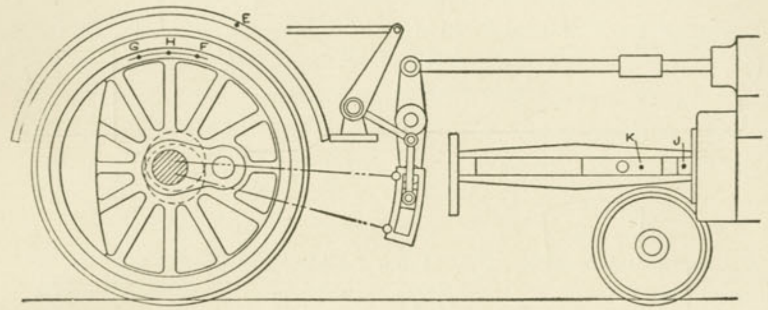


Fig. 35.

METHOD OF PUTTING LOCOMOTIVE ON CENTER.

the front guide block as a center, scribe the arc K on the crosshead. Now turn the wheels ahead past the center far enough to bring the arc K back of the tram point. When the other end of the tram is in the center punch mark J, turn the wheels slowly backward until the arc K has the same position that it had. Then its position can be found by holding one point of the tram in J and stopping the wheels when the other point reaches the arc.

Now scribe the arc C on the tire, using E as the center. With dividers bisect the distance between G and F and get the point H. Having found the point H, the pin is now a short distance below the center. Throw the reverse lever back as far as it will go, then turn the wheels backward until the tram will reach from E to H, and the pin is then exactly on dead center. The valves can now be set.

Referring again to Fig. 34, take the valve tram, and from the point A scribe an arc on the valve rod. The distance that this arc is from D indicates the position of the valve as regards the lap or lead for backward motion. Now bring the wheels back until the crank pin is about six inches above the dead center. Then put the reverse lever in full forward motion, and bring the crank around again to its dead center. With the valve tram again set at A, draw another mark on the valve stem. The distance that this point is

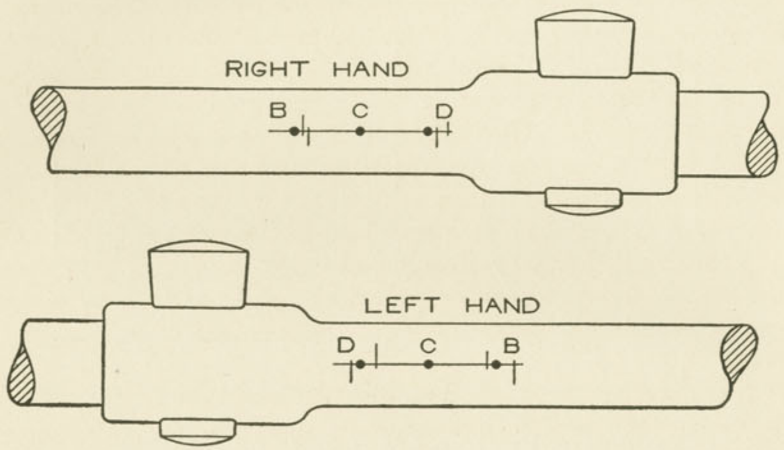


Fig. 36.

METHOD OF ADJUSTING LENGTH OF ECCENTRIC RODS.

from F will give the amount of lap or lead the valve has in forward motion. If the arc comes between the port marks, it indicates lap, if outside it indicates that the valve is at the point of cut-off; and since the valve is to travel equal distances each way, it follows that by measuring the distance from B and D to these arcs it may be determined how much the eccentric rods require to be lengthened and shortened. An enlarged view of the right and lefthand rods, which have been marked as shown in Figs. 31 and 32, is shown in Fig. 36.

To determine whether the eccentric blades require to be lengthened or shortened, the following rule can be adopted: If in Fig. 36 the marks on the valve rod are both back or both ahead of port marks B and D, the length of the eccentric blades should be altered an amount equal to one-half the sum of the distances between the port marks and the arcs. If one mark is back and the other is ahead of their respective port marks, the length of the blade should be changed an amount equal to one-half the difference of the distances between the port marks and the arcs.

Suppose the distances as shown in Fig. 36 give $\frac{1}{4}$-in. lead on the forward port mark and 1-16-in. lap on the back port mark. Therefore, the blade must be shortened one-half the sum of these distances, or 5-32-in. This will square the valve for the right forward motion; that is, the motion will be equalized in either direction from midtravel. After the blade is shortened 5-32-in., it will be found that the valve has moved ahead that distance from its former position, so that by deducting the 1-16-in. lap from 5-32-in. which the motion is changed leaves 3-32--in. lead at the back end also. Assuming that the valves require 1-32-in. lead, it will be found that to make the proper adjustment will require the right eccentric blade to be shortened 5-32-in. and the lead to be reduced 1-16-in.

The right backward motion should be next examined. Suppose that in this case the measurements show that the valve has 1-16-in. lead at the forward end and $\frac{1}{8}$-in. lap at the back. The right backing blade must therefore be shortened $\frac{1}{2}$ $(\frac{1}{8}+\frac{1}{16})=$ 3-32-in. This will square the valve for the right backward motion; but there will be 1-32-in. lap at both ends when 1-32-in. lead is required. Therefore, the blade must be shortened 3-32-in. and the eccentric turned ahead to get 1-16-in. more lead.

The two left eccentric motions should then be examined and data secured which will also square the left valve. The length of all the eccentric rods should then be adjusted and the eccentrics set, but before doing so it will be necessary to have lead marks on the valve rods for a guide. These are shown at M and N in Fig. 37, and are 1-32-in. from B and D.

Put the engine again on the center and move the eccentrics upon the driving shaft until the lead marks come opposite the tram, which has its center on the frame A as shown in Fig. 32. Care should be taken in this operation so that no lost motion enters into the setting. The lost motion should be taken up by moving the eccentrics in the direction in which the engine is to run. This is a very important matter in taking up the lost motion for either forward or backward motion. The valves now have the same amount of lead on both ends and the engine is square. The eccentrics should next be secured firmly to the shafts, care being taken that they are not moved in any way during this operation.

Another important matter that should be investigated be-

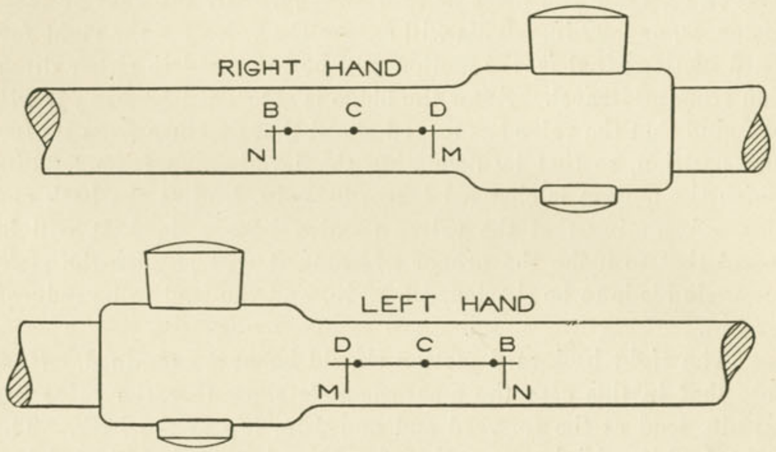


Fig. 37.

Lead Marks on Valve Stem.

fore being sure that the valves are set properly is the position of the points of cut-off in each cylinder. While it is not usual to find locomotives cutting off in both cylinders at the same portion of the stroke, owing to the irregularity of the valve gear, yet at the same time it is advisable, as far as possible, to obtain the same distribution in both cylinders. As a locomotive performs the principal part of its work with the reverse lever hooked back towards the center notch, and with the valves cutting off at early points in the stroke, it is more important that the steam

should be equally distributed with the lever in the working notch than with it down in the corner.

Should the cut-offs be unequal after the valves are set for equal lead, it may often be advisable to change the length of the backward eccentric blades, thus sacrificing equality of lead and cut-off in the back gear to obtain a more perfect motion in the forward gear, as a locomotive, except it be a switching engine, does the greater portion of its work in the forward gear.

To examine the valves for equal cut-offs, put the engine on dead-center, and throw the reverse lever in the position in which it is generally used. Then move the engine until the tram, which has its center at A, Fig. 31, falls into the point D. This will indicate the point of cut-off, and the position of the crosshead should be marked on the guide. Perform this operation for the other end of the cylinder and both ends of the opposite cylinder. Should the cut-off take place at 7 inches from one end and 8 inches from the other, then to equalize the cut-off the valve tram should fall into the points B and D when the crosshead is 7½ inches from each end of the stroke. This latter distance should be laid off on the crosshead guide and the crosshead brought up to the mark. With the valve tram a small line should be drawn on the valve stem from A, Fig. 31. This mark will come a slight distance from D, and will show how much the eccentric blade should be shortened or lengthened. The cut-off should be equalized for the other side in the same manner.

The most difficult part of the valve-setting will here be met with if the equalized cut-offs in each cylinder vary considerably. In order to overcome this unequal condition, one of two things may be done, either lengthen the link hanger on the one side or shorten it on the other. If it is decided to lengthen the link hanger on the side which gives the shortest cut-off, the following method may be adopted: Put the reverse lever in same notch that it was when the cut-off in forward gear was found. Measure the distance from any stationary point to the center of the pin to be moved. Now move the engine ahead until the crosshead comes to a point which will give the same cut-off for both cylinders; that is, if it cuts off at 8 inches on one side and 9 inches on the other, bring the crosshead to a point 8½ inches from one end of the stroke. Now move the reverse lever about 4 notches, and with the point of the valve tram in center A move the lever back until cut-off occurs, as indicated by the tram. Now measure the distance again from the same stationary point to the center of the upper hanger pin. The difference between this distance and the former distance is the amount the hanger must be lengthened to equalize the cut-off on both sides. This change slightly affects the operation of the valves in back gear, and while it may not exactly equalize the cut-off, it will bring it near enough for all practical purposes.

On account of the space taken up by the piston rod, it may sometimes be advisable to have the cut-off take place later in the back end than in the front end of the cylinder, if it is desired to have the same volume of steam admitted to each end of the cylinder. From these pointers it can be seen that, while it is not absolutely important that everything should be exactly equalized when setting the valves, they should always be kept in mind, and any changes in the parts of the valve gear should be made with that object in view.

In order to determine at which part of the stroke exhaust opening and closing take place, the inside lap or inside clearance can be laid off from center C, Fig. 32. The engine should then be revolved and the position of the crosshead noted when these marks come opposite the valve tram whose center is at A.

The maximum port opening and maximum travel of the valve may be found as follows: Place the reverse lever in full gear, then move the wheels one complete revolution. With the valve tram in center A, Fig. 31, mark the extreme travel of the valve in each direction. The distance between the extreme points indicates the maximum travel of the valve, and the distance from either extreme point to the port mark indicates the maximum port opening. The minimum travel and minimum port opening may be obtained in the same manner by placing the reverse lever in the center notch of the quadrant, revolving the wheels one revolution and noting with the tram the distances traveled.

In the setting of valves on a locomotive the most accurate method is to use an indicator, which will give every event of the steam distribution for each different position of the reverse lever.

Old Types of Locomotive Valve Gear. Ever since the time of the earliest locomotive, attempts have been made and are still being made to improve the type of valve gear. Some of them have been partially successful and some have failed entirely. Among some of the older types of locomotive valve gear which possessed merit, but which did not succeed in replacing the Stephenson motion, are the Gooch, Allan and Hackworth valve gear. Each of these types possesses some distinct advantage, but their disadvantages far outweigh their advantages, so that they are only important as showing the tendency in the improvement of locomotive valve gear.

Gooch Valve Motion. The Gooch, or stationary link motion, might be said to be the opposite of the Stephenson motion, in that the valve rod or link block is raised and lowered in reversing the engine, instead of the link in the latter. It is operated with two eccentrics set in the same relation to the crank as in Stephenson's gear, and the link is curved to a radius equal to the length of the valve rod or radius bar turned with its convex side to the axle. This motion gives a constant lead, and has otherwise no advantage over the Stephenson gear, except, possibly, that the link block and the radius bar are lighter to lift in reversing than the link; but it presents an objectionable feature in that the sweep of the radius bar in its raising and lowering is obstructed by the front driving axle when the main connection is made to the second or third pair of wheels, and this is probably the principal reason why the Gooch gear has been in little use and is now practically abandoned in locomotive service.

Allan Valve Motion. The Allan motion may be said to be a combination of the Stephenson and Gooch gear, as the link and valve rod are both moved in opposite directions, so that the angularities and distances in either direction are reduced to one-half of those in either of the other motions under comparison, with an increase of lead amounting to about one-half of that obtained by the Stephenson gear in linking up the engine. For this reason the Allan gear has been the favorite valve motion in continental Europe for a generation or more.

With properly selected lengths of lifting arms of the reverse shaft, the link is made straight instead of curved as is the previous cases, which, in manufacturing in former days, was of no little importance in its favor. The lifting arms are placed on opposite sides of the reversing shafts, which is necessitated by the required opposite vertical motion of the link and valve in changing the cut-off or reversing the engine, and thereby practically balancing each other and holding the reversing shaft in an approximate equilibrium at any position of the reversing lever. These are all properties of considerable advantage over either the Stephenson or Gooch gears.

Although the Allan motion is the most correct one in existence, it has never gotten any foothold in America, probably for the reason that it has, to some extent, the same objectionable feature as the Gooch in regard to the front driving axle, which, however, is not serious, as the short, vertical sweep of the valve rod admits of a bend or a yoke for straddling the axle. As this motion is located inside the frames and occupies about the same place and is of the same weight as the Stephenson gear, on modern engines it would be heavy and cumbersome to apply, so its introduction at this time is hardly to be looked for. These conditions have also made themselves manifest in Europe, and the Allan gear, in spite of its excellent qualities, is fast disappearing from modern locomotives, being displaced by the more advantageous construction and application of the Walschaert motion, which will be referred to later.

The Stephenson, Gooch and Allan motions can be classified as one system, in that they are all based on the two eccentrics set in symmetrical relation to the line of motion, one governing the forward and the other the backward movement of the engine, differing principally only in the matter of lead. In the Gooch gear, with its constant lead, it makes little difference if the rods are crossed or open, but in the Allan and Stephenson it is important that the rods are always open, so that there is no reduction of lead in linking up, as crossed rods will reduce the port opening at the earlier cut-off and cause an unfavorable wire-drawing of the steam.

Hackworth or Joy Valve Motion. There are various kinds of valve motions that are driven with a single eccentric, among which the oldest probably is that of John Wesley Hackworth, which was designed some time between 1840 and 1850; and while this type in its original form is not suitable for locomotives, it is referred

to as the starting-point for a number of modifications, of which a few will be presented, in the line of its evolution to fairly good valve motions for locomotives under various names of so-called " radial " gears.

In 1879, Mr. Joy applied this gear with a slight modification to a locomotive engine, and it is therefore generally known as Joy's gear. It is largely used in Russia, and to some extent in several other countries, without having gained any predominating use over the Allan motion, which, as said before, until a few years ago was the general favorite in continental Europe. The Joy gear is probably the highest development of the Hackworth motion adaptable to locomotives, and gives a very good steam distribution when properly fitted up; but the effect on the movement of the valve by the vertical play of the main axle on a rough track is not entirely eliminated.

In this arrangement, as well as in the original, and in fact in all modifications of the Hackworth gear, the link block or combination lever fulcrum can be guided by a curved frame (" link," as it has been called, on account of its similarity to the ordinary reversing links), or by a swinging link and arm of approximately the same length as the radius bar where such a construction is applicable.

No principle of valve motion has been so fascinating and subject to so many varieties of construction as that of Hackworth, and a score or more inventors have, with comparably small modifications, found them meritorious enough to connect them with their names.

Newer Types of Valve Gear. Despite the failure of a large number of inventors to improve the design and construction of locomotive valve gears, there are constantly new devices springing up, some of which possess considerable merit. Those which have merit are usually tried out on the different roads, and while they may have some advantages, if they do not give good service, they are quickly abandoned. Several of these newer types of valve gear are the Allfree, Young and Baker-Pilliod, and they are each having a limited use.

The Allfree System of Steam Distribution. One of the newer methods of distributing steam to the cylinder of a locomotive is shown in Figs. 38 and 39, the special features being contained within the valve chambers of the cylinders. It is known as the Allfree system of steam distribution, and is being used more or less experimentally upon a number of roads. As applied to a locomotive, it involves substantially a change of cylinders only, any of the standard valve gears such as the Stephenson or Walschaert being used with it.

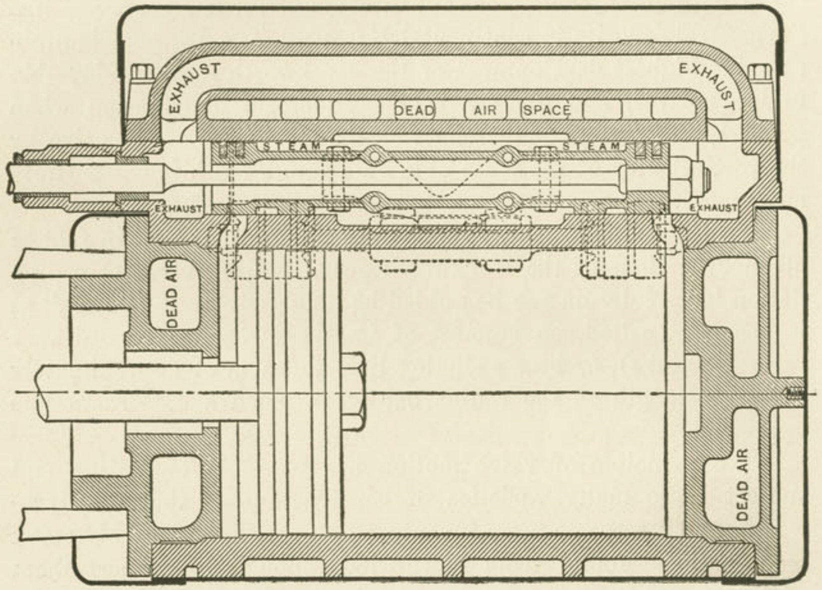


Fig. 38.

Longitudinal Section of Allfree Valve Gear.

In the Allfree system a single valve controls the admission, cut-off and release the same as in a standard engine, except that a sufficient amount of exhaust lap is used to carry the steam to a point that will give a greater expansion. Then to avoid an early closure, a small piston valve, called the compression controlling valve, is introduced through a section of the ports beneath and to one side of the main valve, and has the only function of controlling the compression and providing greater freedom for the escape of

exhaust steam. While the two valves release at the same instant, the compression valve in closing falls about 1¼ inches behind the main valve. This allows the exhaust steam, which would otherwise be in compression, to escape, until the piston reaches about 2½ or 3 inches of the end of its stroke. The clearance being reduced by the use of these valves to about 2½ per cent of the piston displacement, a sufficient amount of compression takes place to cushion the reciprocating parts.

The general arrangement of valves, valve chambers, steam chest covers, etc., is shown in Figs. 38 and 39. The steam chest or main valve chamber is on an angle of 15 degrees with the horizontal and placed close to the cylinder bore. The ports are short and practically straight, which permits of their being scraped. The compression controlling valve chamber passes through the longest section of the ports, and is bushed in the usual way to provide for repairs. The steam chest cover forms the top side of the main valve chamber, and provides a by-pass connection between the exhaust passages which equalizes the exhaust pressures.

The main steam valve is of the rectillinear form, balanced for all speeds and pressures. The compression controlling valve is a piston valve of the usual design. It takes its motion from the main valve by means of an arm connection of rigid construction.

The admission of steam to the cylinders and the cut-off is controlled by the main steam valve. Steam is admitted along the entire lower edge and up one side, thus providing a large port area for admission. Exhaust is also controlled by the main steam valve; but to this is added the exhaust of the compression controlling valve, which releases simultaneously with the main valve.

The cylinder and valve chamber are one casting. The admission is from the inside, which brings the live steam in contact with a considerable portion of the cylinder walls, while the exhaust steam is at the ends and insulated from the live steam. Double walls are used around all live steam passages wherever practicable, with the object of making the insulation as perfect as possible.

The steam chest cover and pressure plate have a by-pass chamber connecting with each end, thus permitting a portion of the exhaust from one end to flow through the passages at the opposite end, which aids in preventing the induction of cinders when drifting. There is also a dead air space provided between this by-pass chamber and the face of the cover, which insulates the live steam from the exhaust steam, and the exhaust steam passing through the by-pass insulates the dead air chamber from the atmosphere.

The general construction of this device consists in substituting for the knuckle pin joining the valve stem to the rocker arm

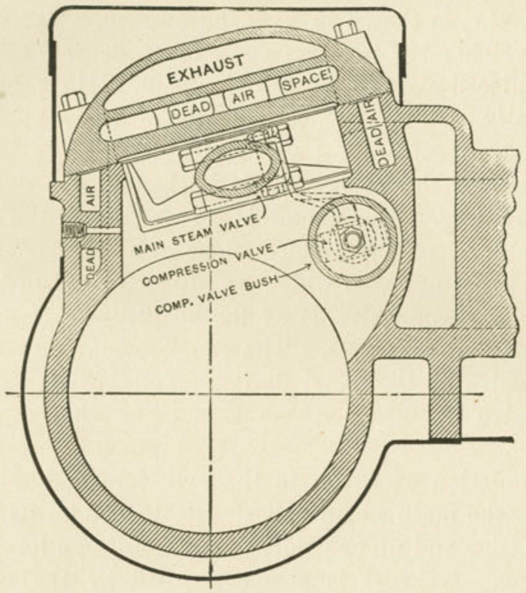


Fig. 39.

Transverse Section of Allfree Valve Gear.

a small crank shaft, to which crank the valve stem is connected and the shaft left free to revolve in the rocker arm bearing. To this shaft a pinion is keyed engaging a toothed wheel sector oscillating on the rocker shaft by means of a lever connection from the crosshead. This gives a composite motion to the valve, namely, one direct from the eccentrics and one from the crosshead, transmitted by the rotation of the crank on the knuckle pin shaft in such a way that the two motions coincide at the opening and

closing moments, but are in opposition at the extreme travel of the valve when the latter is nearly at a standstill, while the main crank passes through a comparatively large angle with a uniformly open port, and the closing of the valve is rapidly accelerated in the same manner as the opening, causing a quick and sharp cut-off. The exhaust and compression are similarly affected by this alternating, accelerating and retarding motion of the valve, delaying the exhaust and compression even at early cut-offs. The advantage is greatest at high speed, when a relatively high average pressure is obtained, which again is dependent on the capacity of the boiler. It is quite complicated to attach, especially on certain types of engines, when the driving wheels are straddled by the guide yoke, and thereby limiting the space required for the rocker arms and bearings.

Among the advantages claimed for it are reduced heat losses, less steam used for a given cut-off, high ratio of expansion, more perfect exhaust, reduced negative work and increased turning moment. These advantages are all supposed to be derived from the insulation of the steam passages, the small waste places in the cylinders, increased length of exhaust, and the higher mean effective pressure.

Young Valve Arrangement. This gear consists chiefly in the application of the Corliss valves to the locomotive engine, with one valve for both the steam inlet and the exhaust at each end of the cylinder. Each valve is provided with double admission and exhaust ports. The steam ports are practically opposite each other, and the relation of the edges of the ports in the valve to these ports corresponds to that of the valve edges to the steam ports of the ordinary slide valve, forming the steam laps, lead and exhaust laps or clearances, as the case may be. The exhaust cavity is a passage diametrically through the valve, of sufficient width on one side to combine both steam ports with the main exhaust port simultaneously during the exhaust period. At right angles to the exhaust passage is a similar but somewhat larger cavity, which corresponds to the steam chest, with transverse passages through the valve body alternating with the exhaust passages, and the lap and exhaust edges are surrounded by carefully fitted slats, both on sides and ends, to prevent leaking.

The motion is transmitted through a pivoted wrist plate to the valve from an ordinary Stephenson valve motion. By means of pivoting the wrist plate on the arm of a bell crank, whose other arm is connected with a union rod to a short arm on the reverse shaft, the wrist plate is raised and lowered by the motion of the reverse lever, producing a moderate increase in lead, an earlier exhaust and later compression than the direct Stephenson motion produces in linking up the engine.

The main advantage of this valve is the quicker admission, closing and exhaust it accomplishes, due to the double port openings, and the small resistance it offers to the valve motion, as compared with the slide valve, in being completely balanced. In

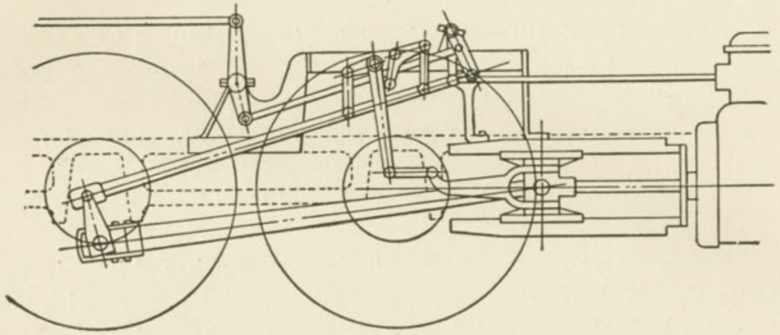


Fig. 40.

Baker-Pilliod Valve Gear.

common with the Allfree gear, it gives a higher average pressure at high speeds than the ordinary valve. This gear, as well as in the previous case, involves additional complications over the ordinary gear, requiring special skill, both in its manufacture and adjustment, which, to some extent, counterbalances the above-named advantages.

The Baker-Pilliod Valve Gear. A new type of valve gear for which many things are claimed is the Baker-Pilliod valve gear shown in Fig. 40. It has only been recently designed, and has been equipped on several locomotives, and it is being tried out on

them. Inventors claim that it is much better than either the Stephenson or Walschaert gear, in a number of different respects.

The motion of the valve is derived from two independent sources, the main crank by connection to the crosshead, and from an eccentric crank opposed at right angles to the main crank. A swinging lever or radius bar is suspended from a reversing yoke, movable to any desired angle to impart the required throw and cut-off. The lever action of the eccentric arm actuates the lap and maintains a constant lead. The crosshead connection imparts the motion of the lap and lead when the swinging lever or radius arm and the reversing yoke are in their central position. Therefore, in midgear with the reversing lever in the center notch, this is practically all the motion imparted to the valve.

By moving the reverse lever forward, the angle of the reverse yoke is changed and brought into combination with the main, imparting motion toward the eccentric arm, whereas the opening motion of the valve is accelerated for the forward motion of the engine. For the backward movement, the reverse yoke is changed to an opposite position, while the path of the valve rod remains the same as for the go-ahead movement. This type of valve gear is adaptable for all classes of valves.

Among the advantages claimed for the Baker-Pilliod valve gear are the following:

First. The weight of the gear is sixty per cent lighter than the Stephenson link gear, and forty per cent lighter than the Walschaert.

Second. It is applicable to all types of engines; it is outside of the frame, which makes it accessible; it requires no special design for the various types of locomotives in use, which reduces first cost and facilitates repairs.

Third. The motion of the valve is obtained from a very low throw, so that the speed has no destructive effects upon the reciprocating parts of the valve gear, which are made as light as experience has allowed. Each and every connection of the gear is mechanically positive, as there are no sliding or lifting joints on link blocks.

Fourth. The reverse requires no change in the reciprocating parts—merely a movement of the positive-connected radius-arm, which overcomes all objections to any type of valve gear that employs a link movement.

Fifth. It maintains uniform lead at all points of cut-off, and only requires a travel of about five per cent of the piston to have full port opening.

ACCIDENTS TO VALVE AND VALVE GEAR.

Broken Slide Valve Yoke or Stem. In the event of a slide valve yoke or stem becoming broken inside of the steam chest, the valve is always forced to the forward end of chest. With an outside admission piston valve or a slide valve, place the lever in a forward gear, and watch the steam leaving the cylinder cocks. Reverse the lever, and if the steam issues from both cocks on one side and from only the back one on the other, the latter has the disabled valve. With the inside admission, steam would issue from the front and not from the back cylinder cock. Where relief valves are used, remove them first and watch movement of valve.

After locating a breakage of this kind, the engine should be put in safe running order as follows: If the engine has relief valves on front end of chest, disconnect valve rod, and, after forcing valve to central position to cover ports, clamp stem from one end, and block with a plug driven into relief valve of sufficient length to hold valve in place, leave up main rod and proceed. If relief valve were on back end, the chest cover would not have to be taken up, but back end of main rod would have to be disconnected and crosshead blocked ahead. The disconnected valve rod would hold the valve against forward end of chest.

Broken Slide Valve. With the ordinary slide valve, which is broken so that the steam ports cannot be successfully covered, remove valve entirely and block with hard wood, having the grain of the wood crosswise of the seat. With the chest filled with blocking, so that the cover will close down on it firmly and make a steam-tight joint, proceed on one side without disturbing anything except the valve rod.

If it is a balanced slide valve, and it is broken so that the steam ports cannot be successfully covered, slip a heavy piece of sheet iron between valve and valve seat, and block valve front and

back. The balance plate will then come down solid on valve and prevent leakage to cylinder.

Broken Link Saddle Pin. In case of link saddle pin breaking, put the lever in a notch forward where it would be safe in starting a train. Then raise the link on the disabled side to the same level as the good one, and block between top of link block and link. Have another block ready of sufficient length to raise the link enough, should it be necessary to back up the engine. With one link blocked up, reversing the engine must be guarded against, unless the disabled side has been changed by raising or lowering to correspond with the good side.

Slipped Eccentric. If the eccentric has slipped, a lame exhaust will be determined. With a bad slip, one of the exhausts will disappear entirely, and by watching the crosshead to note when the exhaust takes place, it can be determined which eccentric has slipped. Having located the eccentric, if it is a go-ahead, move the engine so that crosshead will come very near to the end of its travel ahead. Then move the eccentric around pointing in the opposite direction to the back-up, leaning either toward or from the pin, which would depend entirely on the style of valve, and whether direct or indirect motion. As soon as steam appears at front cylinder cock, tighten set-screws.

For back-up eccentric the lever and crosshead will have to be placed in the opposite direction. The best way is to mark eccentrics before starting, by placing the lever in forward notch and having crosshead at front end of travel. Then make a mark on crosshead and guide, doing the same with eccentrics and straps. If from any cause an eccentric slips and engine is placed so that mark on crosshead corresponds with that on guide, the marks on three of the eccentrics will correspond with those on straps, while the fourth or slipped eccentric's mark will be some distance away from mark on its strap.

Broken Eccentric Strap or Rod. In case of a broken eccentric strap or rod, take down the other strap and rod, cover ports and leave main rod intact.

Lower Rocker Arm or Link Block Pin Broken. Unless the link interferes, all that is necessary is to remove broken part of the arm, cover ports by placing valve in central position and leave main rod up; otherwise the eccentric straps and rods would have to come down. With a broken link block pin, there is more or less danger of interference between link and rocker arm. Take down eccentric straps and rods only, and cover port.

Blows Through Valves or Pistons. When the valve has been placed to cover both steam ports and no steam escapes from cylinder cock, but escapes through exhaust port to stack, it indicates that valve strips are down or broken, and permit steam to escape through small hole in valve to exhaust port.

If valve covers ports and steam appears at both cylinder cocks, it indicates a cut valve or seat.

If piston is at beginning of stroke and valve uncovered, and steam escapes from cylinder cocks at opposite end also from which it is admitted, it indicates leaky packing rings or cut cylinder.

A valve blow continues during the entire travel of valve, while a cylinder blow is strongest when piston is at beginning of stroke, and gradually diminishes until cut-off takes place as piston nears end of stroke.

If a simple engine should blow badly and be unable to start the train when on the righthand dead center, the blow would be on the left side, since that is the only power the engine has to move the other side off the dead center.

QUESTIONS ABOUT VALVES GENERALLY ASKED ENGINEERS.

1. Describe a piston valve.

A. A piston valve is a cylindrical spool-shaped device having cast iron packing rings sprung into place on the valve, and operating in a cylinder of equal diameter. The valve cylinder is provided with suitable admission and discharge ports, and permits the valve to perform the same functions as an ordinary slide valve.

2. What is a balance slide valve? How is it balanced and why? For what reason is the hole drilled through the top of the valve?

A. A balance slide valve is one where a certain percentage of the steam pressure exerted on the top of the ordinary slide valve has been prevented.

The balancing feature is obtained by a steam table extending beyond the extreme travel of the valve, and either bolted to the steam chest cover or cast in one piece with it. The Allan-Richardson valve has its valve grooved for the reception of four snugly fitting strips, which are supported against the table by semi-elliptic springs, which make a steam-tight joint, and prevent any pressure reaching the enclosed part of the valve. The American balance valve obtains the same results, but uses circular, tapering rings supported by coiled springs.

The small hole in the top of the valve is for the express purpose of allowing any pressure or water which may have accumulated on the top of the valve from whatever cause to escape to the exhaust port.

3. What is meant by inside and outside admission valves?

A. By inside admission valve is meant one where the steam enters the steam port of the cylinder from the inside edge of the valve, and is exhausted from the outer edge of the valve. By outside admission is meant one where steam enters the steam port from the outer edge and is exhausted from the inner edge, similarly to our common slide valve, which is an outside admission valve.

4. What is the relative motion of main piston and valve for inside admission valve and for outside admission valve?

A. With inside admission the motion of the valve is in the opposite direction to the piston's motion at the beginning of the stroke. With outside admission the movement of the valve is in the same direction as the piston at the beginning of the stroke.

5. What is the difference in the valve motion for outside admission valves and inside admission valves?

A. Both may have either direct or indirect motion, according to the position of the eccentrics on the shaft and the type of rocker arm used.

6. What is a direct motion valve gear? What is an indirect motion valve gear?

A. A direct motion valve gear is one that transmits the motion of the eccentric to the valve direct, by means of a transmission bar or its equivalent connecting with the valve stem.

An indirect motion valve gear is one where the power is transmitted from the eccentric through the truck to the lower rocker arm, which gives motion to the upper arm that moves the valve rod connecting with the valve stem.

7. What is meant by lead?

A. Lead is the amount of opening a valve has when the piston is at the beginning of the stroke.

8. What is meant by steam side lap?

A. By steam side lap is meant the amount of the valve overlaps the steam ports when the valve is on the middle of the seat.

9. What is meant by exhaust side lap and by exhaust side clearance?

A. Exhaust side lap is the amount the inner edge of the valve overlaps the steam ports when the valve is in the middle of the seat.

Exhaust side clearance is the amount the inside edge of the valve comes short of covering the ports when the valve is in the middle of the seat.

10. With an indirect valve motion, what would be the position of the eccentric relative to the crank pins? With direct motion valve gear? Why?

A. If the valves are the inside admission indirect, necessitating a rocker shaft, the eccentrics would lean toward the fire-box when the main pin is on the forward dead center; while an outside admission indirect has the belly of the eccentrics leaning toward the main pin.

With an inside admission direct and a transmission bar, both eccentrics lean toward the pin; while with the outside direct the eccentrics have the same position as with the inside indirect. With the inside admission indirect, the eccentric rods are crossed when the crank pin is on the forward dead center; the eccentric rods with the outside admission direct are also crossed when the crank pin is on the forward dead center.

These positions of the eccentrics are necessary with the corresponding valve motion to secure movement of the valves.

11. What effect would be produced upon the lap and lead by changing the length of the eccentric rods?

A. Changing the length of the eccentric rods will either increase or decrease the travel, or produce an uneven travel of the

valve over the ports, causing either a too early or too late admission and release. It depends entirely on whether one or both rods have been shortened or lengthened. It affects the engine in that a too early admission on one end would give a too early release, and a too late admission a too late release on the other end. Changing the length of the eccentric rods does not affect the valve lead. Positive lead can only be obtained by advancing the eccentric toward the pin with the ordinary slide valve and indirect motion, while negative lead under similar conditions requires the eccentric to be turned from the pin.

12. Why are eccentric rods made adjustable?

A. To allow for adjustment of the valve travel, so that even steam admission may be made at both steam ports.

REVIEW QUESTIONS.

VALVES AND VALVE GEAR.

1. What two general types of valves are in general use?
2. What are the principal functions of a valve?
3. What is meant by the angular advance of an eccentric?
4. What is valve travel and how is it obtained?
5. For what purpose is overtravel used?
6. Why is lead given to an engine, and how much lead is generally given?
7. What are the effects of increasing the lap on a valve?
8. Why is it necessary to have a small amount of lead on an engine, and what would be the effect of giving an engine too much lead?
9. Of what advantage are the valve diagrams, and why are they used?
10. Describe briefly how you could construct a valve diagram showing how to lay off the angle of advance, the eccentricity, the lap, and how you could obtain from these dimensions the lead and the cut-off.
11. What are balanced valves and why are they used?
12. Name several different types of balanced valves in use on American locomotives.
13. What are piston valves, and what advantages do they have over the common slide valve?
14. Sketch a piston valve bushing and explain how it is constructed.
15. What diameter of piston valve would you use with a 21-inch cylinder?
16. How are piston valves lubricated?

17. Give six advantages and six disadvantages of the piston valve.
18. Describe briefly how an inside indirect valve motion having a piston valve is set.
19. Name three old-style valve motions which have won an historical interest.
20. Sketch a Stephenson valve motion and name the various parts.
21. How is the travel of the valve changed in a Stephenson valve motion?
22. Is the eccentricity always constant in a Stephenson link motion?
23. How do you determine the length of the eccentric blades?
24. Describe the method for finding the length of a link hanger.
25. Before setting the valves in a Stephenson link motion, what precaution should be taken in reference to lost motion?
26. For what purposes are trams used when setting valves?
27. Describe how you would put a locomotive on dead center.
28. If after setting the valves the cut-offs are unequal, how are the cut-offs equalized in both cylinders?
29. Is it ever advisable to have the cut-off take place later in the back end than near the front end of the cylinder?
30. In what way does the Gooch link motion differ from the Stephenson link motion?
31. Describe several newer types of valve gear which have a limited use in this country.
32. Describe briefly the Allfree system of steam distribution.
33. Give several advantages claimed for the Baker-Pilliod valve gear.
34. Having studied carefully all of the different types of valve gears in use, what would you say are the principal reasons that have caused the Stephenson link motion to be used so extensively?
35. Can either the piston valve, or the slide valve, or both, be used with the Stephenson link motion?
36. What effect has the slipping of the block in the link on the motion of the valve in a Stephenson link motion?

37. Does the valve have any motion when the reverse lever is in the center notch?

38. When the reverse lever is hooked back, does this increase or decrease the lead in a Stephenson valve motion?

39. How would you proceed to run if one of the balanced slide valves became broken?

40. Suppose one of the eccentrics had slipped, how would you find which one it was, and how would you proceed?

41. If the rocker arm or link block pin became broken, what would you do?

42. If the engine blows steam badly, how would you determine on which side it occurs?