

DR. PETER ROSE OF CLARKE SCHOOL OF ENGINEERING

CONTENTS TO TRACTION ENGINEERING

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Clarke
School of Traction Engineering

(By Correspondence)

LESSON WITH QUESTIONS

TYPES OF BOILERS

PART I

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

60

TO THE STUDENT

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CLARKE SCHOOL OF TRACTION ENGINEERING

(BY CORRESPONDENCE)

MADISON WISCONSIN

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CLARKE SCHOOL OF TRACTION ENGINEERING

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INTRODUCTION.

- 1 The term traction engine, like the term locomotive, includes the engine proper, the boiler, the trucks or wheels, and all the fittings that go to make up the complete machine. In stationary and marine practice the boiler and the engine are not considered as a single machine, but are taken separately. The boiler and its fittings including pumps, injectors, etc., make up what is known in stationary practice as the boiler plant, while those parts which transform the force of the steam into work, including cylinder, piston, valve gear, governor, lubricators, etc., constitute the engine.
- 2 The most important part of any steam plant, locomotive, or traction engine, and the one requiring the most care and attention, is the boiler. It is the part of the plant which is the most dangerous to life and property, the part which generally wears out soonest and which is obliged to stand the heaviest strains, especially in traction engine service, and hence demands the most careful consideration on the part of the student.
- 3 Partly on account of convenience in studying and partly because it seems to follow the logical order of events, the boiler in this work will be discussed first and the engine afterward.

PART I.

TYPES OF BOILERS.

CLASSES OF BOILERS.

- 4 The essential parts of a steam boiler are as follows: A water reservoir, steam reservoir, furnace, and chimney, together with numerous valves, pipes, and other fittings.
- 5 The steam reservoir may be, and generally is, included as a part of the vessel containing the water. The furnace is placed within the main shell in some boilers and in others outside. The chimney serves the double purpose of carrying away the products of combustion and furnishing draft to the furnace.
- 6 All those surfaces in a boiler which are covered with water on one side and exposed to the hot gases on the other may be defined as heating surface. Superheating surface is exposed to steam on one side and hot gases on the other.
- 7 Boilers are classified according to the service they are engaged in, as, stationary, marine, locomotive, traction engine, etc. According to construction they are classified in various ways. Boilers fall naturally into two main classes depending upon the course taken by the hot gases; one class comprising those boilers which are provided with a furnace

TYPES OF BOILERS

within their own walls known as internally fired boilers, and the other which is provided with a separate furnace and known as externally fired boilers. The former class includes locomotives, traction engines, Scotch marine boilers and many others; the latter, nearly all those stationary boilers which are enclosed in a brick setting.

- 8 Another mode of classification is based upon the arrangement of water space and heating surface in which all boilers fall again into two classes, the first being composed of shell or tubular boilers and the second of water tube boilers. In the former the hot gases come in contact with the interior tubular surfaces while water circulates about the outside, in the latter these conditions are reversed, water occupies the space inside of the tubes and the hot gases are on the outside. All locomotives, nearly all traction engines, and many stationary and marine engines, belong to the fire tube type. Water tube boilers find a wide application in power and heating plants and in certain classes of marine service.
- 9 There are many different forms of construction of each of these four classes, which differ quite materially from each other and are sometimes referred to as a type of boiler. For example, each of the four classes above mentioned are built in two styles, one having horizontal tubes and the other vertical. Besides these there are numberless other lesser modifications in design which it is not worth while to discuss in a work of this character.

FIG. I.

MULTITUBULAR BOILERS.

- 10 Multitubular boilers are used very largely in stationary practice for nearly all kinds of service. In agriculture they find their widest application in creameries and cheese factories. Fig. I represents a longitudinal section of such a

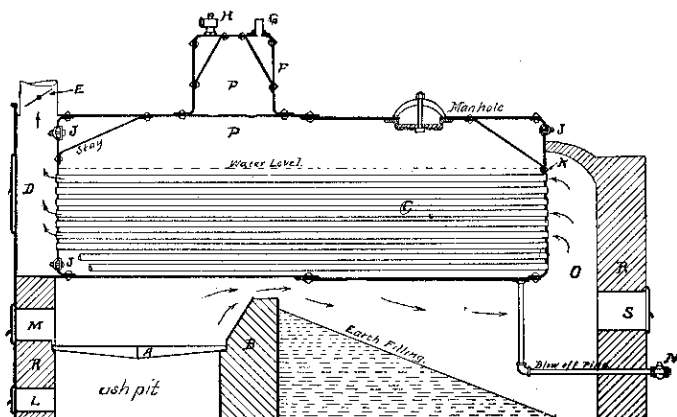


Fig. I Longitudinal Section of Multitubular Boiler.

boiler set in a brick setting. It consists of a main cylindrical shell fitted with tubes usually from $2\frac{1}{2}$ to 4 inches in diameter. The fire is built on the grate A underneath the main part of the shell and the flame and hot gases pass back over the bridge wall B to the combustion chamber at the rear end, and thence forward through the tubes to the smokebox D and out through the chimney.

- 11 The flat ends of the boiler are braced by the flues and usually by a number of diagonal stays in the space above the flues at each end. These boilers are usually provided with a dome, although quite a good many are equipped with a dry pipe instead. The object of the dome and the dry pipe is the same, that is, to insure dry steam. When a dome is used it is usually about as large in diameter as the radius of the main shell and its height is made equal to its diameter. The flat head of the dome is also stayed by means of diagonal stays. While a dome is of considerable advantage in insuring dry steam for the engine, boilers of the other type having a dry pipe, if well proportioned, are equally as effective.
- 12 These boilers are provided with handholes, shown at J in the illustration, by means of which the boiler may be cleaned. A manhole is also provided and is placed either at the rear of the boiler, above the brick work, or, as is more frequently the case, on top of the boiler back of the dome. The manhole provides easy access to the inside of the boiler for cleaning and repairs. The handholes are made about $3\frac{1}{2} \times 5$ inches and are of elliptical shape; the manhole about 11×15 inches, also of elliptical shape so that the cover may be passed through the opening to the inside of the boiler. It is customary to place the fusible plug in the combustion chamber just above the top row of flues and below the water level. The feed water is introduced either through the side near the front, or more often, through the blow-off pipe which is placed at the rear of the boiler, as shown in the illustration.

- 13 The usual method of supporting boilers of this kind is by means of four brackets, bolted to the sides of the boiler, two on each side; one near the front, the other near the back. The rear bracket rests on rollers and the front bracket on a plate set in the brick wall. The object of the rollers is to provide for the expansion of the boiler when heated, and thus prevent the boiler from expanding and cracking the brick wall. The rear end of the boiler is usually set one inch lower than the front end to drain the boiler and to facilitate cleaning.
- 14 The sides of the firebox are made up of the brick walls of the setting. The sides back as far as the bridge wall and the front course of brick on the bridge wall should be made of fire brick. Fire brick usually costs from four to five times as much as common brick, so in many cases common brick is used as a matter of economy, but being exposed to the intense heat of the furnace it has to be repaired quite frequently, whereas fire brick will last for many years and is more economical in the long run.
- 15 The boiler front consists of a large sheet of cast iron to which the fire door, smoke box door and draft doors are attached. The main shell of the boiler is carried out to the cast iron front and forms the smokebox, and an opening is cut at the top to allow the gases to escape to the chimney.
- 16 These boilers are cheap, easy to keep in repair, easy to clean, and when set properly in a good tight setting are about as economical as any boiler made.
- 17 Multitubular boilers contain a relatively large amount of

- heating surface, ample grate area and adequate steam space when properly designed.
- 18 The heating surface consists of the internal area of the tubes and half the outside area of the main shell, together with the area of the two tube sheets not occupied by the tubes.
- 19 The ratio of steam space to water space is about one to two; two-thirds of the boiler is filled with water and one-third with steam; about the same ratio holds also for traction engines.

VERTICAL BOILERS.

- 20 Vertical boilers are used where floor space is quite valuable and where there is plenty of overhead room. They are not generally as efficient as horizontal boilers because the hot gases pass directly out into the air before they have time to give up their heat to the heating surfaces.
- 21 The small vertical boilers used for agricultural purposes do not compare favorably in efficiency with small sized horizontal boilers, but in certain places and for certain kinds of work they are used to a limited extent.
- 22 The boiler shown in Fig. 2 is known as a submerged tube vertical boiler. It is built very much like a direct flue boiler stood on end. The main shell encloses the furnace, water space, and steam space. The grates are placed at the bottom of the shell and the products of combustion pass through the tubes to the cone shaped combustion chamber at the top of the boiler, and then out through the chimney.

- 23 In this style of boiler the water level is maintained above the upper flue sheet and protects both it and the upper ends of the flues from the hot gases. They are also made

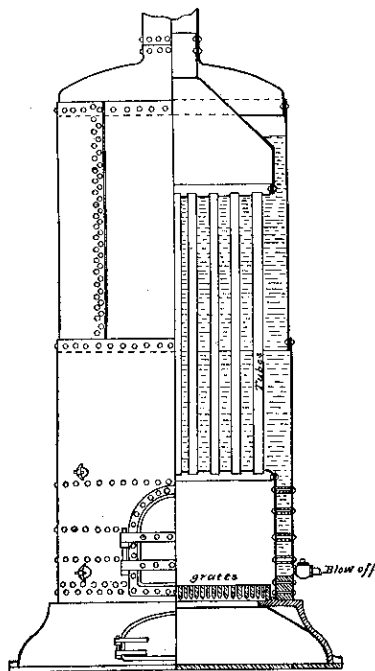


FIG. 2.

with the upper tube sheet placed above the water level. In this case the upper ends of the tubes and the upper tube sheet are apt to become burned and generally give trouble

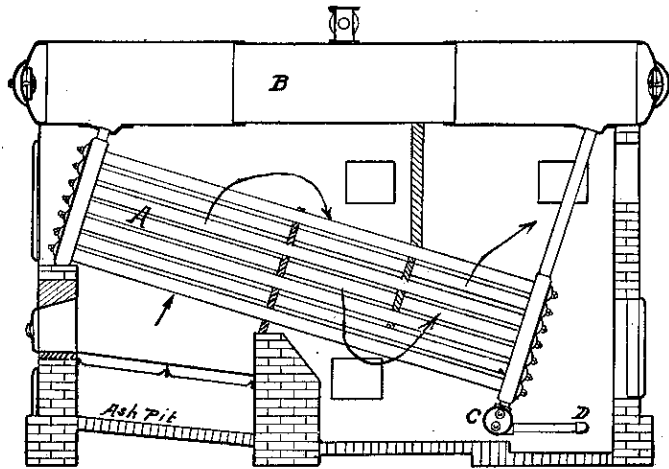
TYPES OF BOILERS

by leaking around the tubes. The furnace walls are tied to the main shell by means of staybolts, which are screwed through both sheets and riveted over, thus forming a water leg all around the firebox. The walls of the firebox and the internal area of the tubes constitute the heating surface. That part of the smokebox above the flues, which is exposed to steam on the opposite side, is superheating surface. Handholes are placed near the bottom of the water leg and also about half way up the main shell to provide means for cleaning. The feed pipe enters near the bottom of the boiler, near which point also, a blow-off valve is located. In boilers of this class, dirt and sediment settle on the lower tube sheet where it is hard to clean, and if not kept clean trouble is apt to occur from burning both it and the ends of the flues.

WATER TUBE BOILERS.

- 24 Water tube boilers are not used very much for agricultural purposes. Only one traction engine is equipped with a boiler of this kind. They find their widest application in large stationary plants and in marine service.
- 25 Fig. 3 represents a leading type of water tube boiler. It consists mainly of a horizontal drum B and a bank of inclined tubes A. These tubes are connected together by means of headers which communicate with the drum B by means of a large pipe at each end. The tubes are inclined at rather a steep angle and are entirely filled with water, the water level standing near the middle of the drum B.
- 26 The water in the tubes rises when heated, passing to the front end of drum B, where steam is given off. The back

connection provides for continuous circulation. Water is pumped into the rear end of the drum B and passes downward to the lower header. Mud and scale settles into the drum C which is provided with handholes at each end to



Sectional View of Water Tube Boiler.

FIG. 3.

facilitate cleaning. The blow-off pipe is shown at D. Fire brick arches are placed across the tubes at two places, shown in the drawing, for the purpose of compelling the gases to pass across the tubes several times, following the course shown by the arrows. These boilers are set in a brick setting and are provided with an iron front similar to the multitubular boilers.

27 Advantages claimed for water tube boilers are that they are quick steamers and less liable to dangerous explosions than fire tube boilers. In case an explosion does occur, usually only one or two tubes will let go, in which case no great danger would be apt to occur. Of course, when such an accident does happen, the boiler has to be shut down before repairs can be made, while if a flue in a water tube boiler breaks it can be plugged without shutting down the works.

28 So far as economy is concerned, water tube boilers rank quite high, but do not surpass the best types of fire tube boilers very much.

TYPES OF TRACTION ENGINE BOILERS.

29 There are only two principal types of traction engine boilers in common use at the present time, viz.: the direct flue boiler and the return flue, with the direct flue distinctly in the lead so far as number is concerned. With only one or two exceptions all traction engine boilers are of the horizontal style and nearly all belong to the fire tube type. Vertical boilers for traction engine work, except in the case of well drilling machinery, have been practically discontinued within the past few years.

THE DIRECT FLUE BOILER.

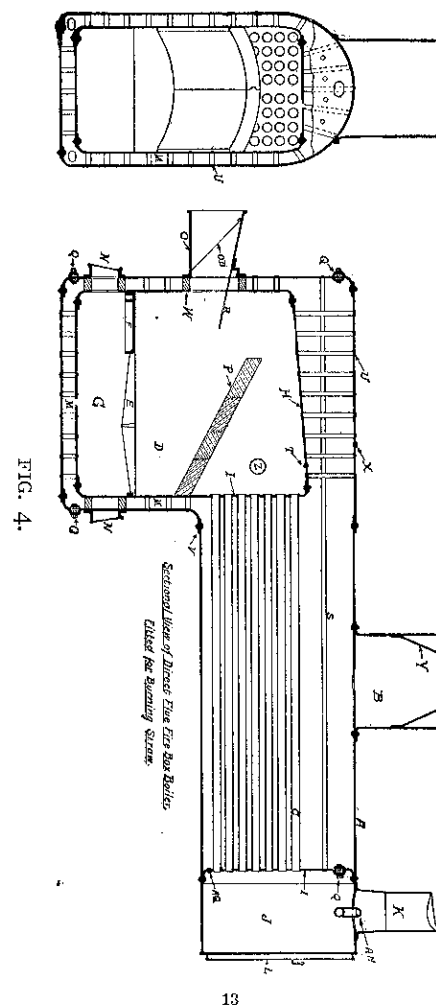
30 The direct flue boiler is used more widely for traction engine purposes than any other type of boiler. It is used exclusively for locomotives and also for stationary work wherever it is desirable to have a self-contained boiler around which a fire brick setting may be dispensed with.

31 Fig. 4 represents a common form of traction engine

boiler of this type, fitted for burning straw. It can be changed to a wood or coal burner very rapidly by putting a door in place of the straw chute O, and by removing the fire brick arch P. Boilers which are made to burn straw, wood, or coal, are called *universal boilers*, of which the one shown in the illustration is an example.

- 32 The boiler consists of a cylindrical shell A, riveted to a rectangular portion containing the furnace. The furnace box is also rectangular and is fastened to the outside portion by means of staybolts 4 or 5 inches apart. The space between the furnace box and the outer casing, which is about $2\frac{1}{2}$ inches wide, is called the *water leg*. The fire is built on the grate E and the hot gases pass up over the fire brick arch and through the tubes C, to the smoke box J, and thence out through the chimney. The water level is maintained about 3 inches above the highest point of the crown sheet H.

- 33 This boiler belongs to the internally fired class and when properly designed and made is fairly economical in the use of fuel. Recent tests of locomotive boilers in St. Louis showed efficiencies very slightly inferior to the best forms of stationary boilers. Traction engine boilers are perhaps a little more wasteful of fuel than the best locomotive boilers.



34

TABLE IN CONNECTION WITH CUT OF BOILER, FIG. 4.

A—Shell	P —Fire Brick Arch
B—Dome	Q —Handholes
C—Flues	R —Fingers for guiding the straw
D—Fire-box	S —Through Stay
E—Grates	T —Fusible Plug
F—Dead Plate	U —Staybolts
G—Ash-Pan	V —Waist Seam
H—Crown Sheet	W —Reinforcing rings about openings
I —Flue Sheets	Y —Diagonal Stays
J —Smoke Box	Z —Small Side Door on side of boiler for
K—Chimney	cleaning the end of the flues.
L—Smoke Box Door	AQ—Cleaning Plug
M—Water Leg	AN—Exhaust Nozzle
N—Draft Doors	OD—Door in Straw Chute
O—Straw Chute	

35

ADVANTAGES OF THE DIRECT FLUE BOILER.

It is small in diameter, neat in appearance, and easy to fire. The large amount of heating surface in and around the firebox where the heat is most intense, together with a large grate area, makes this boiler a quick, easy steamer. The chimney on the front end makes it more convenient and comfortable for the engineer and leaves the entire rear end of the boiler free for the arranging of valves and levers in the most convenient position.

36

DISADVANTAGES OF THE DIRECT FLUE BOILER.

Among its defects may be mentioned the numerous joints in and about the firebox and the large number of flat sur-

faces which require braces and staybolts to hold them in position. It is a fact admitted by all good engineers that there should be no joints exposed to the direct action of the fire. The double thickness of metal at such points makes it difficult for the heat to pass through and consequently there is danger of burning one of the plates. The presence of staybolts, while necessary in all firebox boilers, introduces undesirable features. They impede the circulation, make the boiler hard to clean, and offer a convenient place for corrosion to begin. The unequal expansion between the firebox and the outer shell, due to the extreme differences in temperature, throws heavy strains on the boiler plate and staybolts, which is apt either to break a staybolt or cause a leak where it penetrates the plate. In case a bolt breaks, very heavy strains come upon the unsupported portion of the plate and upon the adjacent staybolts.

37

In ascending or descending grades the crown sheet is apt to become dry, in which case the intense heat in the firebox is apt to do it permanent injury. However, in spite of all these apparent defects, this type of boiler is very popular. It has stood the test very well in actual use.

THE RETURN FLUE BOILER.

38

The most common form of return flue boilers used for traction engines is illustrated in Fig. 5. It consists of a cylindrical shell containing one large flue and a number of small tubes. The large flue contains the grates. The products of combustion pass through the main flue to the

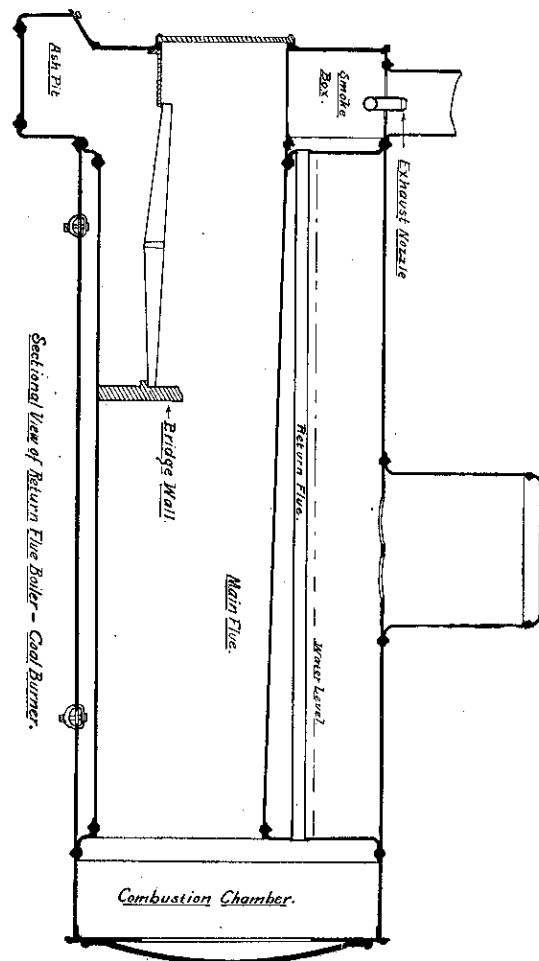


FIG. 5.

combustion chamber, and thence backward through the small tubes (commonly called return flues) to the smoke-box and out through the chimney. Water completely surrounds the main flue and should stand at a depth of 2 or 3 inches above the smaller flues. The size of the main flue ranges from 24 to 28 inches in diameter in all boilers built east of the Rocky Mountains, and the small flues from 3 to 4 inches in diameter. In one style of boiler, built on the Pacific Coast, the main flue is sometimes made upwards of 4 feet in diameter and is corrugated, as shown in Fig. 6, to make it strong enough to resist the external pressure, due to the pressure of steam inside the boiler.



FIG. 6.

ADVANTAGES OF THE RETURN FLUE BOILER.

- 39 Its straight cylindrical form, together with the absence of flat plates and staybolts, make this one of the strongest traction engine boilers on the market. Having no staybolts or braces within the water space, the circulation is good and the boiler is easy to clean. Its compact form offers a minimum of exposed surface for radiation and tends toward economy in the use of fuel. It is also claimed that there is less danger of fire from sparks with this boiler than

with the straight flue type, due to the greater distance and numerous turns taken by the hot gases before reaching the outer air. Another good feature about this boiler is the fact that there is no low hanging firebox to catch obstructions in the road.

DISADVANTAGES OF THE RETURN FLUE BOILER.

40 Among the principal defects of this type of boiler may be mentioned the small grate surface, rather limited heating surface, small ash pan, large main flue, large outer shell, and the chimney on the rear end.

41 The small grate area makes these boilers rather slow steamers in getting started, and the small ash pan requires careful attention on the part of the fireman to keep the grates from burning out, due to ashes piling up in under them. The large main flue is an element of weakness if made very large, for it is a well known fact that the larger the flue is, with the same thickness of metal and same length, the less able it is to withstand external pressure. Where very large main flues are used they are reinforced either by staybolts, by corrugating, or in some other way. Some trouble has been experienced in traction engine boilers by the collapsing of the main flue. Where this has occurred, however, the results have not been very serious to life or property.

42 The large main flue necessitates the use of a boiler shell of large diameter. This is objectionable because the larger the diameter of a boiler, with the same thickness of plate, the weaker it is, a fact which will be proven in a subse-

quent lesson. The presence of a smokebox and chimney on the rear end is objected to by some engineers on the plea of comfort and because this arrangement makes it difficult to obtain the most convenient arrangement of valves and levers.

ADAPTATION OF THE RETURN FLUE BOILER AS A STRAW BURNER.

43 When it is desired to burn straw the fire door and grates may be removed and the attachment shown in Fig. 7 substituted; in this case the grates, which are merely fingers, are placed a little above the center of the main flue.

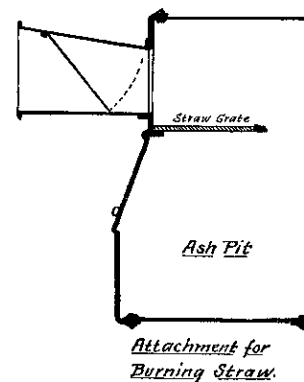


FIG. 7.

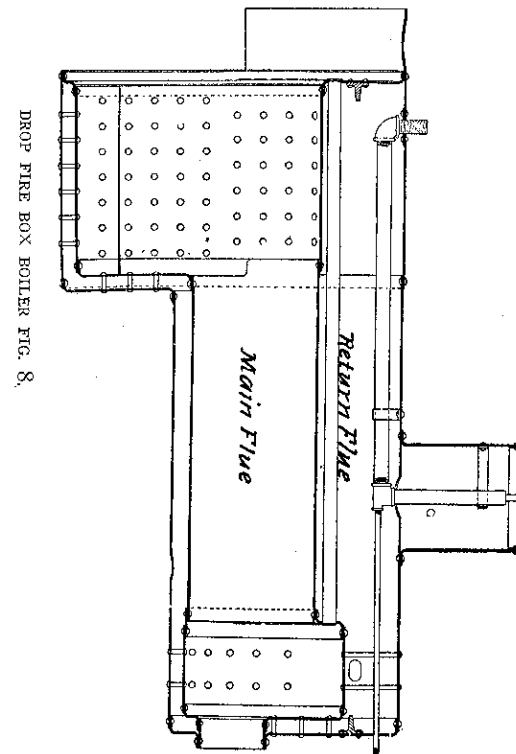
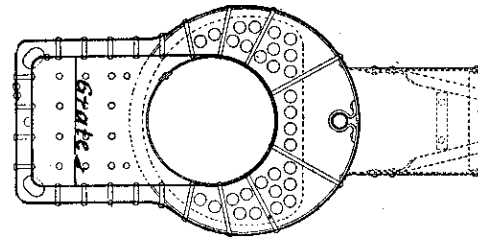
44 For a number of years the return flue boiler was considered the most successful straw burner; in fact, the first really successful straw burner was a boiler of this general

type. Since it was discovered that a direct flue boiler would burn straw just as well as coal, by means of an arch, the return flue boiler has fallen largely into disuse. It is, however, a very good boiler and closely resembles the Scotch marine boiler which has been very popular for a great many years in stationary practice and on vessels.

THE FIREBOX RETURN FLUE BOILER,

- 45 Or, as it is frequently called, the drop firebox boiler, is a rather old type of traction engine boiler and is still built by some of the leading manufacturers in the United States.
- 46 The essential features of this boiler are shown in Fig. 8. It resembles the direct flue boiler in having a fire box at the rear end, but otherwise it is almost identical with the return flue type of boiler. Fire is built on the grates in the fire box, and the smoke and hot gases pass forward to the combustion chamber at the front end from which they return through the small flues to the chimney at the rear end. This boiler is provided with what is known as a water front, that is, a water space extending almost completely around the combustion chamber. The upper wall of this chamber consists of a flat plate which may be cleaned through a handhole in the shell of the boiler. The walls of the firebox as well as the main flue and the walls of the combustion chamber are braced with numerous staybolts. Since this boiler contains nearly all of the features common to the two types previously discussed it follows that it must also combine most all of their advantages and disadvantages.

TYPES OF BOILERS



THE HOLT BOILER.

47 Fig. 9 is a diagrammatic view of one form of boiler made by the Holt Manufacturing Co. The fire box extends under the main shell just as it does in the multitubular boiler described on a preceding page, and in this respect it is unique among traction engine boilers. The grates are shown at A and the bridge wall at B. The latter consists

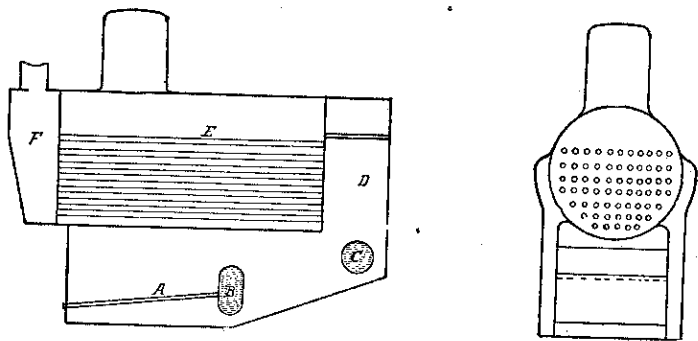


FIG. 9.

of an elliptical tube in communication with the water space of the water leg to whose sides its flanged ends are riveted. The tube C adds increased heating surface and acts as a brace for the front end of the combustion chamber.

48 This boiler has an immense amount of heating surface, which is included in the cross tubes B and C, in the walls of the firebox, bottom of the main shell and all of the flues E.

TYPES OF BOILERS

THE WESTINGHOUSE BOILER.

49 The Westinghouse boiler, shown in Fig. 10, is worthy of mention inasmuch as it is the only water tube boiler used

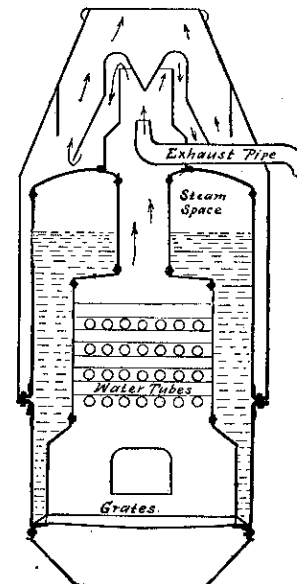


FIG. 10.

for traction engine purposes. This boiler consists of a vertical shell surrounding a central portion which contains the furnace and water tubes. The latter are placed horizontally in courses at right angles to each other and cir-

culuation is provided for by means of baffle plates at the ends of, and between the sections, which causes the water to pass from one set of tubes to the other. The hot gases pass through the central part of the boiler through the space occupied by the water tubes. The outer shell is bolted to the lower portion and encloses the main water space, and the steam space at the top.

- 50 This boiler is a quick steamer and quite efficient, but for traction engine work requiring a large amount of power it is manifestly not very well adapted to the large sized rigs used in the West.

THE "BEST" BOILER.

- 51 The "Best" boiler is another form of boiler used on the Pacific Coast. It is a combination of both the vertical and horizontal boiler and is built in the form of an L. The horizontal part contains the furnace and the vertical part the fire tubes. The two views in Fig. 11 show up the construction of this boiler clearly enough to require no further explanation.

MATERIALS USED IN CONSTRUCTION.

- 52 Almost all manufacturers' literature specifies the materials used in construction of their boilers and engines. This fact makes it desirable to include a discussion of materials of construction in the following pages.
- 53 The principal materials used for boiler work are iron and

TYPES OF BOILERS

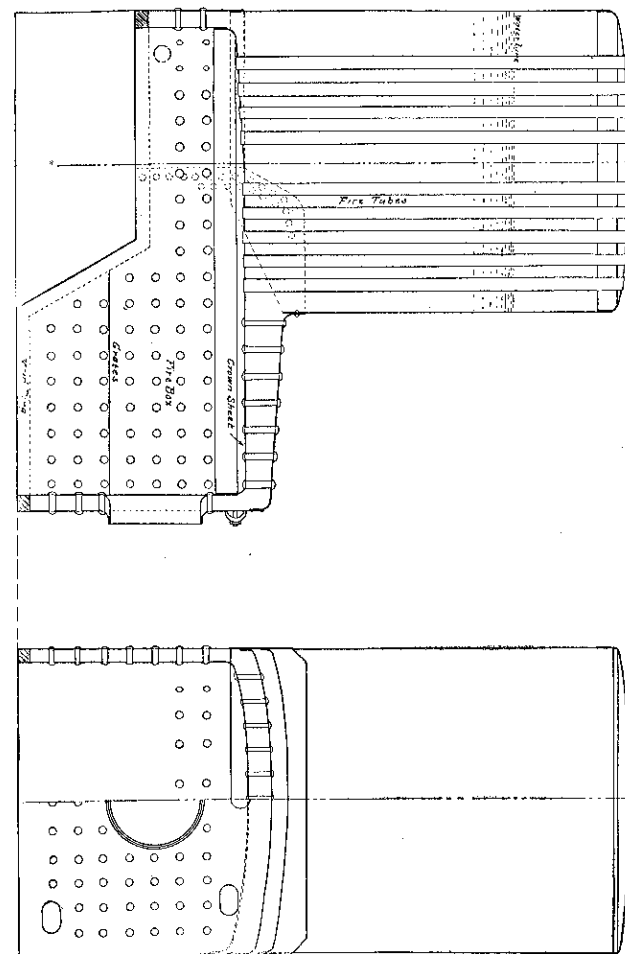


FIG. 11.
SHOWING THE CONSTRUCTION OF THE "BEST" BOILER.

steel. In the early days of boiler making, iron was used almost exclusively but during the past thirty years nearly all boilers have been made of steel. The only notable exception to this rule is found in certain classes of low pressure boilers used for house heating. Many of these boilers are made of cast iron, in sectional form, and are designed only for low pressures, ranging from 5 to 15 pounds per square inch.

54 CAST IRON.—Cast iron is brittle and untrustworthy. It resists corrosion very well but cracks easily when exposed to considerable differences in temperature. In high pressure boilers it is used to a considerable extent for brackets, and manhole and handhole cover plates, although during the past few years pressed steel shapes have taken its place to a large extent. The tensile strength of cast iron per square inch is from 15,000 to 22,000 pounds, i. e., a bar one inch square will require a force of from 15,000 to 22,000 pounds to pull it in two. Its crushing strength is much higher, ranging from 80,000 to 120,000 pounds per square inch in short sections. Gray iron castings, which are considered best, are made of the best grade of pig iron.

55 MALLEABLE CAST IRON.—Malleable castings are first made like ordinary white castings and then packed in a substance rich in oxygen and placed in an oven where they are maintained at a bright red temperature for several days. During this time a large amount of the carbon, which is always present in cast iron, is either burned out or changed from the graphitic to the combined form. It is this uncombined carbon and the loose structure of the iron that

makes ordinary cast iron so brittle. When the carbon is removed the iron is more like wrought iron or steel and becomes quite malleable.

56 Malleable castings are used largely for agricultural machinery and for the light brackets on some traction engines. It is much more expensive than ordinary cast iron, due to the process of manufacture.

57 WROUGHT IRON.—Wrought iron is used in traction engine work, mainly for the reinforcing rings around the fire door openings and at the bottom of the water leg, and to some extent for braces. It resists strains due to unequal expansion better than almost any other substance and does not crack. Wrought iron differs from steel in having a fibrous structure. When broken, the fibres are clearly seen and between them dark particles of impurities called slag which have not been squeezed out in the process of working. The only way to tell the difference between wrought iron and steel is by the appearance of the fracture. Wrought iron has about the same tensile strength as steel.

58 STEEL.—The principal difference between wrought iron and steel lies in the process of manufacture. Carbon is an essential of steel, but not of iron, and it is this substance that gives it its hardness and the ability to take a temper. In mild steel, such as is used for boiler work, the percentage of carbon ranges from .15 to .20 of one per-cent. Steel of this kind will not take a temper. Machinery steel, which is the kind used for shafting, contains about $\frac{1}{2}$ per cent of carbon and may be made to take a mild temper. Steel containing from .8 to 1 per cent of carbon is the kind that is

used for saws, axes, cold chisels, and other tools of the same nature. The finer varieties of tool steel used in the manufacturing of knives, razors, etc., contains from $1\frac{1}{4}$ to $1\frac{1}{2}$ per cent of carbon and is very brittle.

59 Mild steel is easily welded and worked in the forge but not quite as easily as wrought iron. Steel or iron containing sulphur is brittle when hot and is hard to weld, in which case it is said to be "hot short." If phosphorus is present in appreciable quantity it is "cold short," i. e., brittle when cold.

60 TESTING STEEL.—The suitability of steel for boiler purposes is determined by certain chemical and physical tests. The chemical test is for the purpose of determining the amount of carbon, sulphur, phosphorus, and other elements which affect its strength and ductibility.

61 PHYSICAL TESTS.—Physical tests may be divided into two classes, the tensile test and the bending test. For the tensile test, strips are cut from the boiler plate about 2 inches wide and 18 inches long. These test pieces are marked out in one inch divisions over a portion 10 inches long in the middle of the piece. After this the test piece is put in a machine, which pulls the strip in two, and registers the tension on a scale beam. The specimen will stretch as soon as the load is applied, but up to a certain point will return to its original length when the load is removed; the point at which it loses its elasticity and will not return to its original length when the load is removed, is called the *elastic limit* of the metal and corresponds roughly to about one-half of the final breaking strain.

THE BENDING TEST.

62 The bending test is performed in two ways. One method is to bend the test piece over on its self and hammer it down cold, and in the other, the piece is heated to a cherry red, plunged in cold water, and then bent over on its self in the same way as for the cold test. In either test, boiler plate up to 7-16 of an inch thick should show no cracks or flaws on the outside of the bend.

BOILER STEEL SPECIFICATION.

63 Steel for boilers is classified by the manufacturers as extra soft steel, fire box steel, flange steel, and rivet steel.

64 *Extra Soft Steel.*—Extra soft steel will stand a breaking strain of from 45,000 to 55,000 pounds per square inch, and has an elastic limit ranging from 22,000 to 27,000 pounds per square inch. It should stretch 28 per cent of its length in a space of 8 inches before breaking. It must also stand both of the bending tests specified above. It must not contain more than .035 of one per cent of phosphorus or .03 of one per cent of sulphur.

65 *Fire Box Steel.*—Fire box steel has an ultimate tensile strength ranging from 52,000 to 62,000 pounds per square inch, an elastic limit of half this amount, and must stretch 26 per cent in a length of 8 inches. The bending test and tests for phosphorus and sulphur are the same as for the extra soft steel. This steel is used for the walls of fire boxes, as the name implies.

66 *Flange Steel.*—Flange steel has the same ultimate

strength and elastic limit as fire box steel, but the required elongation in a length of 8 inches is only 25 per cent. The maximum amount of phosphorus allowable is .06 per cent and of sulphur .04. The bending tests are the same as those specified above.

- 67 *Rivet Steel*.—Rivet steel must have the same properties as extra soft steel.

TESTS FOR BOILER TUBES.

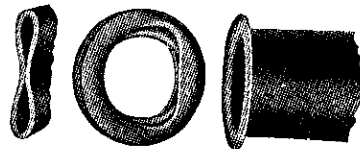
- 68 Boiler tubes must be made of charcoal iron or mild steel and be either lap welded or solid drawn. They must be straight, round, free from defects and stand an internal water pressure test of 500 pounds to the square inch.

- 69 A test section cut from one tube taken at random from a lot of 150 must stand crushing down cold vertically without showing cracks or flaws. The length of the test section varies with the diameter of the tubes as follows: Three-fourths of an inch for tubes between 1 and $1\frac{3}{4}$ inch in diameter; 1 inch for tubes between 2 and $2\frac{1}{2}$ inches; $1\frac{3}{4}$ inches for tubes between $2\frac{3}{4}$ and $3\frac{1}{4}$ inches for tubes between $2\frac{3}{4}$ and $3\frac{1}{4}$ inches; $1\frac{3}{4}$ inches for tubes between $3\frac{1}{2}$ and 4 inches.

- 70 All tubes must also stand flanging and beading without cracks or flaws.

ILLUSTRATION OF TEST TO WHICH BOILER TUBES ARE SUBJECTED.

Fig. 12.



QUESTIONS.

1. What does a traction engine include?
2. Why is a boiler the most important part of a steam plant?
3. Enumerate the principal parts of a boiler.
4. Define heating surface, superheating surface.
5. How are boilers classified as to service?
6. State how boilers are classified in regard to the direction taken by the hot gases.
7. State the arrangement of water space and heating surface in (a) fire tube boilers, (b) water tube boilers.
8. For what purposes are multitubular boilers adapted?
9. Describe the course taken by the hot gases in a multitubular boiler.
10. How are multitubular boilers braced?
11. What is the object of (a) the dome, (b) the dry pipe?
12. What provision is made for cleaning boilers?
13. How are multitubular boilers set and supported?
14. What surfaces are considered heating surface?
15. Mention two types of vertical boilers.
16. Name some of the defects of vertical boilers.
17. Mention the advantages of a water tube boiler.
18. Name the two principal types of traction engine boilers.

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19. How may a direct flue coal boiler be changed to a straw burner?
20. What and where is the water leg?
21. Mention some of the advantages of the direct flue boiler, (b) some of the disadvantages.
22. Mention some of the advantages of the return flue boiler, (b) some of its defects.
23. Describe the Holt boiler.
24. Describe the Westinghouse boiler; in what particular does it differ from other traction engine boilers?
25. Describe the "Best" boiler.
26. What is the principal material used in boiler construction?
27. Describe the properties of cast iron.
28. What use is made of malleable iron?
29. What are the principal uses of wrought iron for traction engine purposes?
30. What element is an essential part of steel?
31. Explain the effect of the following elements on steel, (a) carbon, (b) sulphur, (c) phosphorus.
32. What are the tests required of good boiler plate?
33. What grades of steel are specified for boiler purposes and what are the characteristics of each?

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LESSON WITH QUESTIONS

DETAILS OF BOILER CONSTRUCTION
PART II

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

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PART II.

DETAILS OF CONSTRUCTION.

GENERAL REMARKS.

- 1 There are three principal processes in common use for the making of steel, viz.: the Bessemer process, the open hearth process, and the crucible process. Railroad rails and steel gears are made by the Bessemer process; boiler plate mostly by the open hearth, and tool steel by the crucible process.
- 2 Boiler plate is rolled in the large plate mills and then shipped to the boiler manufacturer. Here the sheets are cut to the proper size and shape for the work in hand, the edges are planed and the rivet holes located and drilled. In some of the best boiler shops all the rivet holes are located by means of a carefully laid out pattern which is clamped to the sheet being worked upon. In this way the work is accurately done and the rivet holes come exactly opposite one another when the work is completed, thus avoiding the kind of work shown in Fig. 13. In this case, where the holes do not come opposite, a punch is driven in which stretches the metal on opposite sides enough to let the rivet enter. Then when it is riveted down it is deformed in the way illustrated. Such construction is not good since

the metal of the plate is strained with the punch, and the rivet is weakened when headed down. Rivet holes are some times punched but it is considered better practice to drill

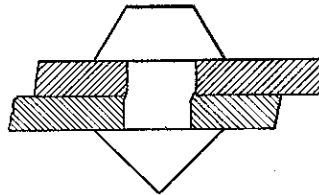


Fig. 13.

Deformed Riveting.

them, since punching destroys the elasticity of the metal around the holes to some extent.

3 The next operation is to pass the plate through the bending rolls where it is bent into cylindrical shape, the amount of curvature being determined by a pattern made for the purpose.

4 Boiler heads and dome heads are usually flanged in a large press. The sheet is first heated all over to a cherry red in a forge, and then the flange is turned, after which it is allowed to cool slowly and the rivet holes are drilled. After all the sheets are drilled and shaped they go to the erecting floor and are first loosely bolted together and afterwards riveted. The rivets are heated to a bright red in a forge, and headed up usually with a steam or pneumatic riveter while still hot. In repair work the rivets are generally headed up by hand. When the rivets cool they contract and draw the plates very tightly together.

5 The furnace box in direct flue boilers is made separately, then blocked up into position in the main shell. The holes for the staybolts are drilled through both the outer casing and walls of the furnace box at one operation and tapped for the threads. The staybolts are then screwed into place, cut the right length, and the ends riveted over cold. After the heads are put in, the braces are inserted, and the tubes placed in position and expanded.

6 In putting brackets on traction engines they are first located by careful measurement and the bolt holes drilled and tapped by using the bracket itself as a template, thus insuring accuracy in the drilling of the holes.

7 All good boiler shops are equipped with plate rolls, plate planers, drill presses, punches, flanging presses, riveters, hoisting machines, cranes, etc.

BLISTERS AND BAGS.

8 When boiler plate was made largely of wrought iron it frequently happened that the plate was not thoroughly welded together in all parts during the process of welding. If a plate containing a fault of this nature were placed in the crown sheet or in some place exposed to the direct

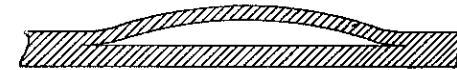


Fig. 14.

Blistered Boiler Plate.

action of the fire it was apt to blister, that is, separate at the point where it was not welded as shown in Fig. 14. While

the same thing may happen with steel plate it is not, owing to the process of manufacture, at all likely to do so. All boiler plate is inspected but imperfections of this character are impossible of detection.

- 9 A bagged plate is illustrated in Fig. 15, and is not due to any imperfection in manufacture, but to improper handling of the boiler. Bagged plates appear in the plates above the fire when they become covered with scale to such an extent that the heat can not pass through into the water fast enough. In this case the metal softens and the pressure of steam in the boiler forms the bag. A bagged plate may result in a boiler explosion but very frequently it does not.
- 10 In the case of either bags or blisters the boiler should be

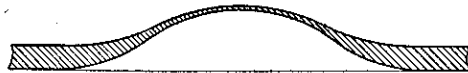


Fig. 15.

Example of Bagged Furnace Plate.

taken to a good boiler shop, where the old plate is removed and another one put in its place. This is much better and safer than patching; in fact, a patch ought never to be put on a boiler where it is exposed to the direct action of the fire. The only places in traction engines where bags are apt to form is in the crown sheet of direct flue boilers and in the main flue of return flue boilers.

PATCHES.

- 11 There are two kinds of patches, called soft patches and

hard patches, the former of which is illustrated in Fig. 16. A soft patch is employed where temporary repairs become necessary and where the leak is small and it is difficult to put on a hard patch. The hard patch is used where it is desired to make permanent repairs.

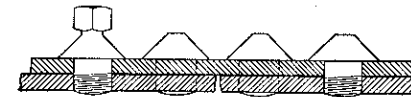


Fig. 16.

A Soft Patch Showing Patch Bolts.

- 12 The soft patch consists of a suitable piece of boiler plate cut considerably larger than the leak it is designed to repair in order to have sufficient margin for the patch bolts which hold it in place. These bolts are simply machine screws having a special form of head illustrated in Fig. 16. When they are screwed into place the square portion may be cut off, leaving a head which looks like a rivet head. In putting on a soft patch the piece is first drilled for the bolts and then bent to the proper form and clamped into position. The bolt holes are then drilled in the boiler shell and tapped, after which the bolts are put in. Before doing this, however, it is customary to put a coating of thick red lead over the patch which helps make a tight joint when the bolts are screwed into place. A patch of this kind would not be permissible in the crown sheet because the double thickness of metal, together with the lead, would not allow the heat to pass through into the water rapidly enough and consequently it would burn out. Where a soft patch is used the

lead should be given three or four days to set before raising steam.

- 13 A hard patch is made by cutting out the injured sheet and riveting a new one over the opening thus made. Instead of putting on a patch of this sort it is better to remove the whole section of plate containing the damaged portion and put a new one in.

RIVETS AND RIVETING.

- 14 Rivets are made of either wrought iron or rivet steel. They are forged from round bars and are given either a round or a pan shaped head. The cylindrical part is

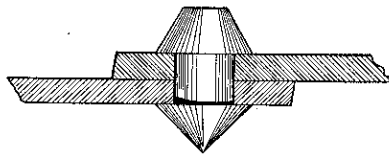


Fig. 17.

Example of Hand Riveting.

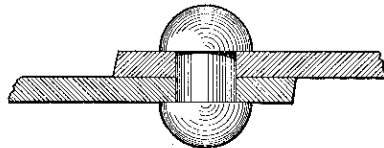


Fig. 18.

Example of Machine Riveting.

slightly tapered and is called the shank. The ultimate shearing strength of rivets, which is the stress they are

subjected to in boilers, ranges from 40,000 to 45,000 pounds per square inch. Rivets are stronger in shear than in tension. Fig. 17 is an example of the form of rivet head made by hand riveting and Fig. 18 of machine riveting.

RIVETED JOINTS.

- 15 A riveted joint cannot be made as strong as the solid plate because it is obvious that the plate is weakened at the joint to the extent of the metal cut out for the rivet holes. It is, therefore, usual to express the strength of the joint as some percentage of the strength of the unpunched plate.

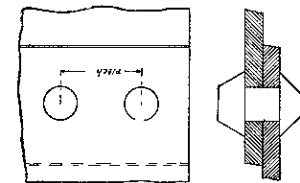


Fig. 19.

Single Riveted Lap Joint.

- 16 Fig. 19 represents what is known as a *single riveted lap joint*. In this case the two plates are lapped over each other and held together with a single line of rivets. The distance from center to center of the rivets is called the *pitch*.
- 17 Rules have been laid down covering the design of riveted joints by which it is possible to determine the size of rivet and the pitch for any thickness of plate and all boiler makers are guided accordingly.

- 18 The transverse seams, that is, the seams passing around the shell in traction engine boilers, are generally made single riveted. The strength of a single riveted lap joint is about 56 per cent of that of the solid plate.
- 19 A *double riveted lap joint* is made the subject of illustration in Figs. 20 and 21. The former is a sample of what is

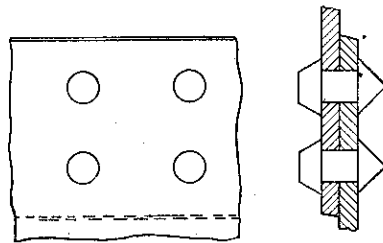


Fig. 20.
Chain Riveting.

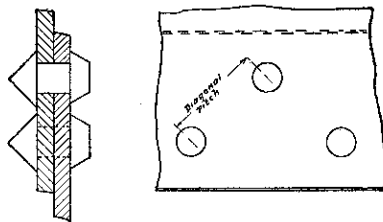


Fig. 21.
Zigzag Riveting.

called chain riveting, the latter of zig-zag riveting. In chain riveting the rivets are placed one behind the other while in zig-zag riveting the rivets are staggered. In zig-zag rivet-

ing the distance between the centers of rivets in different rows is called *diagonal pitch*. This style of riveting is the one most commonly used in traction engine boilers. As stated before, it is customary to single rivet the girth seams in traction engine boilers while the longitudinal seams are always double riveted, and in some very large engines triple riveted, since, as will be presently shown, the stress on the latter is twice that on the former. Waist seams, however, in direct flue boilers, are frequently double or triple riveted to provide against the twisting strains that come upon traction engine boilers at this point. The strength of a double riveted lap joint is from 69 to 75 per cent of the unpunched plate. Fig. 22 shows the usual arrangements of the rivets in all of the various seams of a direct flue boiler.

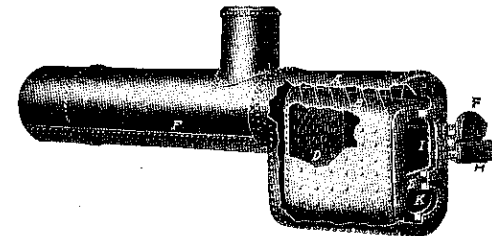


Fig. 22.
Firebox Boiler, Showing Method of Riveting the Joints.

- 20 A *butt joint* is represented in Fig. 23, having a single cover plate. Sometimes two cover plates are used, one on each side of the joint. They may be secured with one, two or more rows of rivets. Butt joints are generally used for

plates one-half inch thick and upwards and since very few plates more than three-eighths of an inch thick are used on traction engine boilers, these joints are not used much for

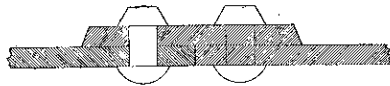


Fig. 23.

Butt Joint, with Single Cover Plate.

this kind of work. In the advent of higher pressures and thicker plates, traction engine boilers may yet be constructed with butt joints. The efficiency of butt joints ranges from 60 to 85 per cent, depending upon their design.

REINFORCING RINGS.

- 21 Numerous methods are in use for forming the joints around fire door openings and at the bottom of the water leg. Figs. 24 to 26 inclusive show the usual method of forming the joint at the bottom of the water leg in open fire box boilers. The heavy wrought iron ring in Fig. 26 is sometimes called the mud ring. It is made extra heavy in some boilers and is used as the principal support for the brackets carrying the boiler. Fire door openings are reinforced in the same way as the bottom of the water leg and also by flanging after the manner shown in Fig. 27. When plates are flanged for any purpose they should be worked at the proper temperature and the radius of curvature should be at least four times the thickness of the plate; shorter bends than this are liable to injure the plate.

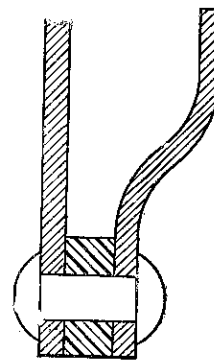


Fig. 24.

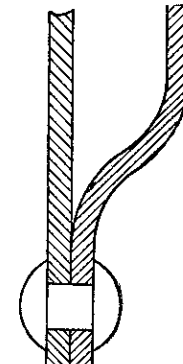


Fig. 25.

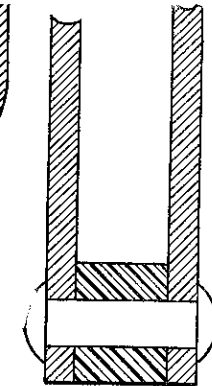


Fig. 26.

Methods of Forming Joint at Bottom of Water Leg.

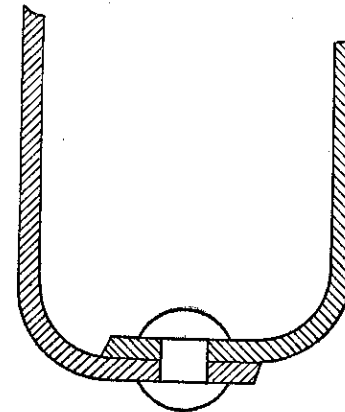


Fig. 27.

CALKING.

- 22 After boilers are riveted together the seams must be calked to make them steam and water tight. The tool used for this purpose and the method of operating it is shown in Fig. 28. In well equipped boiler shops calking is done with a pneumatic calking tool, but in repair work, such a tool as is shown in the illustration, is the one commonly used. The end of the tool should be rounded so as not to groove the under plate. A sharp edged calking tool should never be used. When a boiler begins to leak at a seam or around a rivet head it can generally be made tight by calking. Almost anybody can calk a boiler. A rather heavy hammer should be used for this purpose so that the outer plate will be driven firmly against the under one.

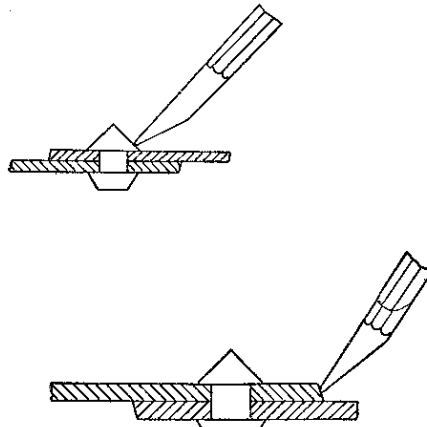


Fig. 28.

DETAILS OF BOILER CONSTRUCTION

- 23 It is never safe to calk a boiler under steam pressure because the sudden shock to the metal, which is under tension, may be sufficient to cause a rupture, ending in a boiler explosion. Sometimes boilers are calked under water pressure. This method is entirely safe, but has not very many advantages. Boiler plate is generally planed to a bevel on the edge to facilitate calking.

STAYS AND BRACES.

- 24 The tendency of pressure within a boiler is to make all surfaces assume either a cylindrical or a spherical shape. All such surfaces, therefore, are self-supporting, while all flat plates are non-supporting and require staybolts and braces to hold them in position. The surfaces that require bracing are the tube sheets, above the top row of tubes, and the flat surfaces of the crown sheet and water leg in locomotive fire box boilers. The number and position of staybolts are determined by rules which have been worked out for the guidance of boiler makers.

STAYS FOR BOILER HEADS.

- 25 That part of the tube sheets occupied by the tubes needs no other supports than the tubes themselves, but the surface above the flues needs staying. This is accomplished by means of through stays, crow foot stays, and girder stays. Through stays consist of straight iron rods passing lengthwise of the boiler above the flues and riveted over at both ends. The number used depends, of course, on the size of the boiler. A through stay is shown in Fig. 4.

DIAGONAL STAYS.

- 26 Fig. 29 shows two styles of crow foot stays. The one on the left is made of a single piece of boiler plate, split and doubled back at the lower end to form the crow foot. It is

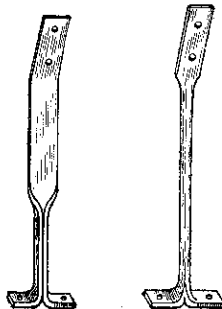


Fig. 29.

Crowfoot Stays.

known as the McGregor stay; being made of one piece of metal and free from welds it is exceedingly strong. The other stay consists of a round bar of iron flattened at one end and having a crow foot welded on the other. When the weld is perfectly made it is a strong, serviceable brace.

- 27 Another method of placing diagonal stays is shown in Fig. 30. In this case two angle irons are riveted to the boiler and stays inserted, as shown. Both the angle irons and the brace help to support the plate.

- 28 *Girder Stays* are shown in Figs. 8 and 37. They consist of heavy tee irons riveted across the plate. All these forms

DETAILS OF BOILER CONSTRUCTION

of braces are used by some of the different makers and appear to be entirely satisfactory.

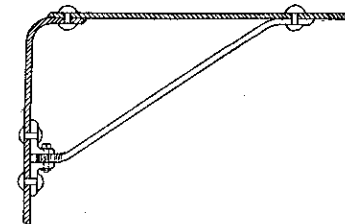


Fig. 30.

Diagonal Boiler Stay.

STAYBOLTS.

- 29 Where the staybolts are short, as in the water leg, they are threaded throughout their whole length and screwed into place, after which the outside end is cut off. Both ends are riveted over usually by hand.
- 30 Owing to the strains of rough roads and of traction to which traction engine boilers are subjected, these stays are

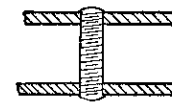


Fig. 31.

Stay Bolt in Water Leg.

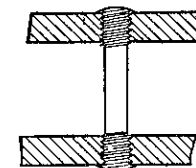


Fig. 32.

Long Stay Bolt.

usually made one-sixteenth of an inch larger in diameter than the rules for stationary boilers demand. Fig. 31

shows one of these stays in position and Fig. 32 represents a form of staybolt occasionally used where a long bolt is necessary to support the crown sheet. In this case the bolt is turned down to the roots of the threads between the threaded portions so that it can be screwed through the first sheet and then pushed on through the hole to the sheet below. With pressures, such as are carried at the present time, the staybolts are required to support about 20 square inches of surface each. This provides for a spacing of about 4 inches apart one way and 5 the other.

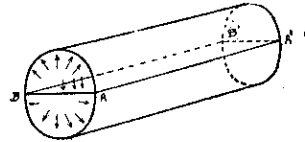


Fig. 33.

A Boiler of Unit Strength.

THE STRENGTH OF A CYLINDER SUBJECTED TO INTERNAL PRESSURE.

- 31 The strength of a cylinder subjected to internal pressure is dependent upon the thickness of the material in its walls and its diameter. Let Fig. 33 represent a boiler of unit length. The arrows represent the direction of pressure exerted by the steam, which is of course equal on all parts of the boiler and acts in a straight line radially from the center. It is evident that the metal which resists the pressure of the steam is found along the lines AA' and BB'. The area of this metal is equal to the thickness of the plate mul-

tiplied by its length. It is also evident that if the boiler were cut in two along the lines above mentioned and a bottom put on the upper half, that, with a given pressure of steam per square inch, the total pressure on this bottom would exactly equal the total pressure acting upward on the semi-circular curved portion of the shell. If the pressure were 100 pounds per square inch, and the boiler were one inch long, the total pressure on the bottom would equal the diameter of the boiler in inches times 100. This product represents the force tending to separate the bottom from the curved portion. It is also equal to the force tending to rupture such a cylindrical boiler along its side seams.

- 32 It is plainly evident from the above considerations that the larger the diameter of the boiler the greater will be the stress on that boiler with the same pressure of steam. Since the metal that resists bursting is the cross-sectional area of the plates along AA' and BB' it is evident that the thickness of the boiler plate must be increased in accordance with its increase in diameter if the boiler of larger diameter is to have the same strength as one that is smaller.

STRESSES IN A CYLINDER SUBJECTED TO INTERNAL PRESSURE.

- 33 Suppose that the boiler in Fig. 33 is 30 inches in diameter, 96 inches long, and that the plates are $\frac{1}{4}$ of an inch thick. The total pressure tending to burst the boiler along a side seam, if the pressure is 100 pounds per square inch, is 100 times 30 times 96, equals 288,000 pounds. The area of metal to resist this force is equal to twice the thick-

ness of the plate multiplied by its length, or, in other words, equal to the total area of the section of the plate along both the lines AA¹ and BB¹. This area is equal to $\frac{1}{4}$ times 96 times 2, equal to 48 square inches. The stress on each square inch, therefore, is equal to 288,000 divided by 48, equals 6,000 pounds; that is, each square inch of metal along the side seams of the boiler, if the pressure is 100 pounds per square inch and the dimensions of the boiler are as above stated, bears 6,000 pounds.

34 *The Stress on a Transverse or Girth Seam* may be found as follows:

35 The area against which the steam can act to pull the boiler in two lengthwise is the area of the boiler-head, which, in this case, is equal to 30 times 30 times .7854, equals 706.86 square inches. This area multiplied by 100 equals 70,686 pounds, which amount represents the total pressure on the boiler head with steam at 100 pounds pressure. The total area of metal to resist this pressure is, of course, equal to the circumference of the boiler times the thickness of the boiler plate; or, stated in another way, it is equal to the metal which would be cut off if the boiler were sawed in two at right angles to its length.

36 The circumference of a 30 inch boiler equals 30 times 3.1416, equals 94.248 inches, which multiplied by the thickness of the plate, $\frac{1}{4}$ inch, equals 23.562 square inches. The total area of metal, therefore, to resist the pressure of 70686 pounds is 23.562 square inches. Consequently the stress per square inch on the metal is equal to 70686 divided by 23.562 or 3000 pounds. This is just half the stress on the

metal along a longitudinal seam. It is this difference in stress that makes it necessary to double rivet longitudinal seams while girth seams are only single riveted.

37 *The Factor of Safety.*—In the design of machinery for buildings it is never safe to figure on the entire strength of the material entering into the construction, hence, a factor of safety is introduced ranging from three or four in some structures, to as high as fifteen or twenty in others; that is, in designing the structure, instead of using the ultimate breaking strength of the material in figuring what the structure will bear safely, some fraction only of the ultimate strength is considered. If the factor of safety is four, only one-fourth of the ultimate breaking strength will be used in computing the strength of the structure; if the factor is ten, only one-tenth of the ultimate breaking strength will be considered.

38 In boiler work it is usual to assume a factor of safety of five, therefore, if the material has an ultimate strength of 60,000 pounds per square inch only 12,000 pounds will be considered in figuring the safe working pressure.

THE BURSTING PRESSURE OF CYLINDERS SUBJECTED TO INTERNAL PRESSURE.

39 Whenever the force tending to burst a cylinder is exactly equal to the strength of the material resisting rupture, that cylinder is on the point of bursting. We, therefore, have the following rule to determine bursting pressure:

40 *Rule I.*—Multiply twice the thickness of the boiler plate

by the ultimate tensile strength and divide the product by the diameter of the boiler, all expressed in inches.

41 *Example.*—Suppose a boiler, without seams, 30 inches in diameter is made of $\frac{1}{4}$ inch plate having a tensile strength of 60,000 pounds per square inch, the force necessary to burst this cylinder is, according to the rule, equal to 2 times $\frac{1}{4}$ times 60,000 divided by 30, equals 1,000 pounds.

42 The safe working pressure of a cylinder will be much less than this because, as indicated above, a factor of safety must be introduced and the strength of the riveted joint taken into consideration. Authorities differ somewhat as to the exact factor of safety to be employed, but it is believed that the general practice among traction engine builders is to use a factor of safety of 5. On this basis we have the following rule:

43 *Rule II.*—Multiply together the thickness of the boiler plate expressed in inches, the ultimate tensile strength and the efficiency of the joint in per-cent. Divide this product by 500 times the radius of the boiler. The result is the safe allowable working pressure for a new boiler.

44 There is no rule for figuring the safe working pressure of old boilers, the pressure allowable depends upon the judgment of the operator or the inspector.

45 *Example.*—The allowable working pressure on the boiler above mentioned is equal to $\frac{1}{4}$ times 60,000 times 70 divided by 500 times 15, equals 140 pounds.

46 The Board of Supervising Inspectors of steam vessels prescribe the following rule for obtaining the safe working

pressure of cylindrical boilers having single riveted longitudinal seams:

47 *Rule III.*—Multiply the thickness of the shell and the ultimate tensile strength and divide by 6 times the radius.

48 Applying this to the above boiler we obtain the following results: $\frac{1}{4}$ times 60,000 divided by 6 times 15, equals 166 2-3.

49 *Kent's Rule.*—Kent's rule is another rule sometimes given for obtaining the safe working pressure. It runs as follows:

50 Multiply the constant number 14,000 by the thickness of the plate and divide by the diameter of the boiler in inches.

51 Applied to the above boiler it gives a safe working pressure of 116 2-3 pounds.

52 It is rather unfortunate that authorities do not agree on rules for figuring the safe working pressure, but an examination of the above results would show that there is considerable difference among them.

53 The working pressure for a boiler having flat plates or flat surfaces cannot be worked out by any of the above rules, because the rules for pressure on flat plates differs considerably from those applicable to cylindrical surfaces.

54 In figuring the safe working pressure of a direct flue boiler, the proper thing to do is to figure the safe working pressure for the cylindrical part, and then for the walls of the firebox, and consider the smaller value thus obtained as the safe allowable working pressure for the whole boiler.

55 The following discussion applies to the safe working pressure on flat surfaces:

CLARKE SCHOOL OF TRACTION ENGINEERING

THE SAFE WORKING PRESSURE ON FLAT SURFACES.

56 The allowable working pressure on flat surfaces may be determined by the following rule. This rule is used by the United States Board of Supervising Inspectors of steam vessels:

57 *Rule IV.*—Multiply the square of the thickness of the plate in sixteenths of an inch by 112, divide this product by the square of the distance from center to center of the stays. The result will be the allowable working pressure for plates 7-16 of an inch and under. If the plates are more than 7-16 of an inch thick use 120 in the place of 112.

58 *Example.*—What will be the allowable working pressure on the walls of a firebox having plates 5-16 of an inch thick with staybolts placed $4\frac{3}{4}$ inches apart?

59 *Solution.*— $5 \times 5 \times 112$ divided by $4\frac{3}{4}$, squared, equals 125 (nearly).

THE SAFE WORKING PRESSURE FOR FLUES.

60 The following rule gives the allowable working pressure on plain flues made in sections not to exceed 8 feet in length. The ends of each section should be flanged and riveted with reinforcing rings between the flanges:

61 *Rule V.*—Multiply the square of the thickness of the plate by 89,600 and divide the product by the product of the length of the section and the diameter of the flue.

62 *Example.*—What is the allowable working pressure on a flue $\frac{3}{8}$ of an inch thick, 20 inches in diameter, 6 feet long?

63 *Solution.*—Applying the rule just given we have $89,600 \times \frac{3}{8} \times \frac{3}{8}$, divided by 6×20 , equals 105.

DETAILS OF BOILER CONSTRUCTION

64 It can readily be seen from these figures that the weakest part of a return flue boiler is the main flue. If made very large it is apt to collapse unless the metal is made exceedingly thick or is supported in some way by reinforcing rings, corrugations, or staybolts.

THE SAFE WORKING PRESSURE ON STAYBOLTS.

65 The safe working pressure on staybolts is limited by the Board of Supervising Inspectors of steam vessels to 6,000 pounds per square inch. Since wrought iron rods will bear a tension of 45,000 pounds before breaking this provides a factor of safety of a little more than 7. To figure the stress on a staybolt, multiply the area which it supports by the steam pressure, and divide this product by the cross-sectional area of the smallest part of the bolt in square inches.

66 *Example.*—Suppose the bolts are placed 4 inches apart one way and 5 the other and the pressure on the boiler is 120 pounds per square inch, the total area supported by the staybolt is 4 times 5 or 20 square inches, and the total load which the bolt carries is 20 times 120 or 2,400 pounds. If the bolt is .7 of an inch in diameter its area is about .4 of a square inch. The stress per square inch, therefore, on the bolt is equal to 2,400 divided by .4 or 6,000 pounds.

✓ EXAMPLES.

- 67 1. Find the safe working pressure on a plain cylindrical boiler 42 inches in diameter whose shell is $\frac{3}{8}$ of an inch thick.
- 68 2. Find the safe working pressure for a return flue boiler whose main flue is 7 feet long, 24 inches in diameter, and $\frac{3}{8}$ of an inch thick. The main shell of the boiler is 48 inches in diameter and made of $\frac{3}{8}$ inch steel.
- 69 3. Find the allowable external working pressure of a flue 48 inches in diameter, 6 feet long, made of 7-16 boiler plate.
- 70 4. A staybolt $\frac{7}{8}$ of an inch in diameter supports a surface $4\frac{1}{2}$ by $4\frac{3}{4}$ inches; allowing 6,000 pounds per square inch as the stress on the bolt, what will be the allowable working pressure in the boiler?
- 71 5. Find the allowable working pressure for a direct flue boiler having the following dimensions: Diameter of the shell 30 inches, thickness of plate in the shell 5-16 of an inch, distance apart of staybolts in the water leg $4\frac{1}{2}$ by $4\frac{3}{4}$, walls of the firebox $\frac{3}{8}$ of an inch thick.
- 72 6. Apply the three rules given for finding the allowable working pressure on plain cylindrical boilers to the following example: The diameter of the boiler is 36 inches, thickness of boiler plate 5-16 of an inch.

PECULIAR STRESSES IN TRACTION ENGINE BOILERS.

- 73 Probably no other boiler is subjected to the same hard usage as the traction engine boiler. It not only has to gen-

erate the steam and carry the steam pressure but it is also subjected in very many cases to the evils of bad water and incompetent management. It is obliged, furthermore, to stand not only the twisting and racking due to rough roads but in most cases it is used as the foundation for a heavy machine weighing anywhere from 5 to 18 tons. As usually designed both engine and drive wheels are bolted to the boiler, together with the necessary gearing for the transmitting of motion from the former to the latter. Thus all the force exerted by the steam in propelling the engine on the road must pass through the boiler.

- 74 A stationary boiler is usually placed in a brick setting and is tended by a man who is trained to the work. All it has to do is to furnish steam and all the stresses it has to bear are the stresses due to steam pressure. A locomotive has somewhat harder work to do. It usually has poorer water to contend with and is racked some by the inequalities of the roadbed, but aside from those two things it has no more work to do than the stationary boiler. The traction engine boiler, on the other hand, has all of these difficulties to contend with, together with bad water, bad management, rough roads, high steam pressure, traction stresses, etc.

THE DOME.

- 75 The object of the dome is twofold. It furnishes additional space for steam and provides a point at considerable distance from the surface of the water from which the steam may be drawn. If steam is taken from near the surface

of the water it will carry with it some water in the form of a fine spray. Steam containing water does not give good efficiency in producing power and is dangerous to the cylinder and valves. Water washes the oil from the valve and valve seat and from the inside of the cylinder causing these surfaces to wear and cut. Besides, since water is incompressible, it is apt to gather ahead of the piston and knock a cylinder head out, therefore, every effort is made to secure dry steam for the engine. The use of the dome is one of the schemes taken to attain this result.

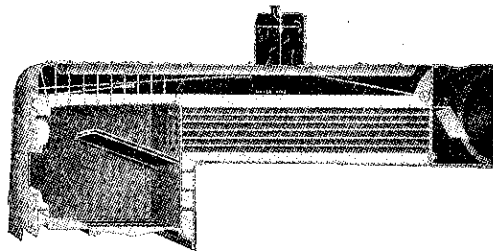


Fig. 34.

Boiler with Baffle Plate in Dome and Deflector in Smoke Box.

- 76 Some manufacturers place a *baffle plate* in the upper part of the dome which acts as a separator. (See Fig. 34.) Steam in rushing upward toward the entrance of the steam pipe, has to turn around the edges of the baffle plate but the entrained water, having more momentum than the steam, is supposed to keep on in a straight line and strike the baffle plate and be deflected back again toward the bottom of the boiler. Communication between the shell and the dome is

secured by cutting one or more openings in the shell. The steam which condenses on the sides of the dome, finds its way back into the boiler through small holes drilled in the shell around the inside walls of the dome.

DRY TROUGH.

- 77 A dry trough is used in some boilers to take the place of a dome. This dry trough, an illustration of which is shown in Fig. 35, is so placed that steam cannot be drawn directly from the steam space in the boiler, but must first pass into the dry trough before it can pass out of the steam pipe. The current of steam flowing into the steam pipe thus causes very little commotion at the surface of the water and the steam that passes through is tolerably dry. Boilers having a dry trough in place of a dome ought to have a little more

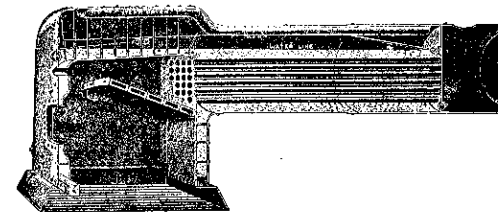


Fig. 35.

Boiler with Dry Trough.

steam space above the top row of flues than boilers with domes. A boiler without a dome makes it a little more convenient for the arrangement of the machinery.

STEAM PIPES.

- 78 In some boilers the steam pipe is carried from the top of the dome outside of the boiler shell to the steam chest; in others, it is carried inside of the boiler. When the steam pipe is placed inside of the boiler the difficulties due to radiation are avoided and the steam will come to the steam chest usually somewhat dryer than if it has to pass through a long outside pipe, no matter how well the latter may be jacketed. This position of the steam pipe, however, frequently causes considerable trouble if it is not properly drained. When the engine is shut down steam condenses in the loop of the pipe and before starting in the morning this water should be drained out.
- 79 In some boilers a stop cock at the end of the pipe is connected by means of a long valve stem so that it may be opened from the outside of the boiler. In other boilers there is no such provision made for drainage, until the boiler cools down, then, by taking out a handhole plate, the drain cock can be gotten at and opened. It frequently happens that the engineer in charge either does not know about the drain cock in the dry pipe or else forgets to open it. In either case the steam pipe freezes and bursts during the winter time, and the next season trouble is experienced from the start, with priming.
- 80 The steam pipe lies either in the water or very close to it and if it is cracked or if the drain cock falls out, as sometimes happens, water gets in and is carried over by the steam to the engine. Here it causes loss of power and in-

jury to the valves and cylinder. The only remedy in this case is to put in a new dry pipe. While it is not absolutely necessary that the dry pipe be drained every morning, it is necessary that it be drained at the end of the season's run when the engine is laid up for the winter.

FIREBOX.

- 81 The firebox of direct flue boilers is made either in the open bottom or closed bottom form. Fig. 35 represents an open bottom firebox and Fig. 4 a firebox with a closed bottom. The open bottom firebox allows the use of a large ashpan and makes it more convenient to enter the firebox to make repairs; entrance to which is easily made from the bottom by taking off the ashpan. The closed bottom firebox is very strong and compact, and is preferable for certain styles of mounting. The water leg in all firebox boilers acts as a mud collector and at the same time affords protection to the furnace walls. Water in rapid circulation will carry a heavy load of sediment; the amount it will carry being dependent upon its speed. Since there is less circulation at the bottom of the water leg than anywhere else in the boiler, it is clear that the mud will collect largely at this place. In using muddy water, unless care is taken to clean the water leg frequently, it is apt to fill with mud, in which case the furnace walls may become seriously burned.

FIREBOX ARCHES.

- 82 Firebox arches are made of either firebrick or iron. If made of iron they are cast hollow to prevent their becoming

ing too hot and burning out. Some form of arch is absolutely necessary in firebox boilers for burning straw but not for burning coal, although in the larger sizes of engines, where soft coal is burned, the use of an arch is often desirable. Arches are used extensively in the fireboxes of locomotives where they are said to give very good satisfaction. An arch is necessary in burning straw because with heavy draft the light particles of straw would be drawn into the flues and clog them up.

83 The action of the arch is very simple. It helps to mix the products of combustion and protects the flues from cooling, due to the admission of air when the fire door is opened. It also acts as a reflector of the radiant heat of the fire and maintains a more constant temperature in the firebox. At the same time it causes the flames to take a longer course through the firebox, thus giving the gases a longer time to part with their heat.

84 In burning straw and certain kinds of soft coal containing considerable volatile matter, very good results are obtained by admitting air above the fire as in the case of the hollow arch or through a draft door in the upper part of the firebox chamber.

WATER TABLES.

85 Water tables are used in place of arches in some boilers. Fig. 36 represents what is known in locomotive practice as the Buchanan firebox. This table extends completely across the firebox and has an opening cut near the upper part through which the flames pass into the combustion cham-

ber. Another form of water table is in use in which the table extends only part way up across the firebox, the rest of the arch effect being obtained by using two or three sections of firebrick above the water table.

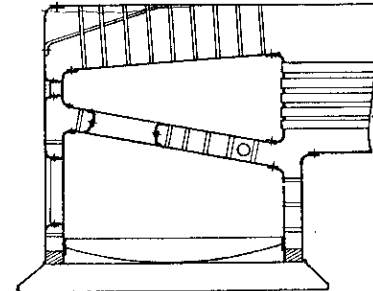


Fig. 36.

Boiler with Water Table.

86 Means for cleaning the water table are provided in the shape of handholes on the sides of the firebox. While the rapid circulation of the water in the water tables ought to prevent the accumulation of scale or sediment, it is a well known fact that it does not always do so, and it is advisable to clean the water table very frequently, because, if scale does form at this point, the intense heat of the fire will certainly burn out some of the plates. With arches that do not extend entirely across the firebox, difficulty is sometimes experienced by the formation of steam in the upper portion which forces the water back and thus allows the plates to become burned. In the type of firebox shown in the illustration, no such difficulty is liable to be met with. Owing

to the numerous joints in the heat of the fire and the unequal expansion between the water table and the firebox walls it is difficult to prevent leakage.

- 87 The use of a water table adds quite a large amount of heating surface to a boiler, but at the same time it provides a cooling surface in the firebox at a point where it is desirable that the heat should be most intense. This leads to incomplete combustion in many cases, since it is a well

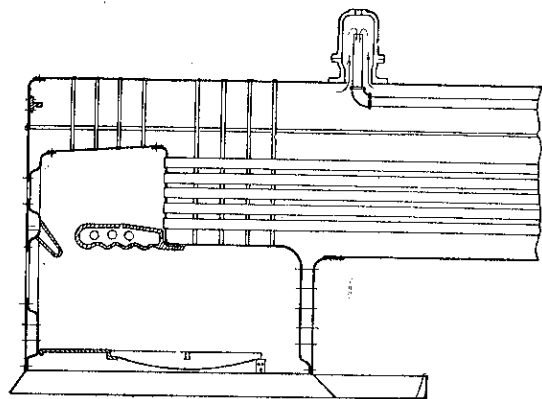


Fig. 37.
The Abell Fire Box.

known fact that the difference in temperature between the flames and the firebox walls may be anywhere from 1,500 to 2,000 degrees.

THE ABELL FIREBOX.

- 88 The Abell firebox is represented in Fig. 37. The peculiar feature of this boiler is that the flues extend back to about

the middle of the firebox, thus making a flue considerably longer than the ordinary and so providing for more heating surface in the boiler. The flame passes up over a baffle plate into the combustion chamber and then passes out through the flues. Handholes are provided on the sides of the firebox for cleaning the lower crown sheet. In using muddy water these should be made use of freely.

CHIMNEY.

- 89 The chimney is built of either cast iron or of sheet steel. When made of the latter material it is frequently provided with an inner lining, which protects the outer casing, and which can be easily renewed when burned out. Cast iron is somewhat more durable than sheet steel or sheet iron for chimney purposes because it resists corrosion better. When sheet steel is used it is joined to the boiler shell by means of a casting. Fig. 38 is a section of a cast iron chimney, or stack, as it is sometimes called.

THE SMOKE BOX.

- 90 The smoke box is located at the front end of direct flue boilers and at the rear end of return flue boilers. In both cases the smoke passes into the smoke box before passing out through the chimney. In most boilers it is formed by a continuance of the boiler shell, but some manufacturers make a separate smoke box of cast iron which is fastened by means of bolts to the main shell. Either method of construction is entirely satisfactory.

- 91 The object of cast iron smoke boxes is to provide a material which is not affected very much by the hot gases. Some smoke boxes are provided with a baffle plate or de-

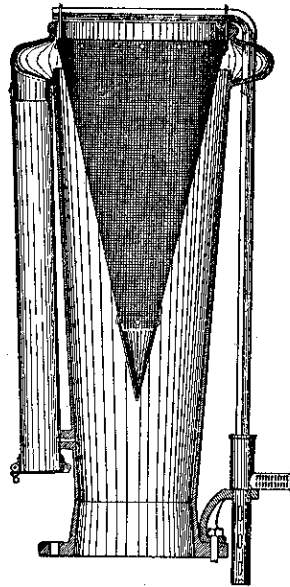


Fig. 38.

Cast Iron Chimney.

flector, whose object is to compel the smoke to pass through all of the flues, and to regulate, to some extent, the intensity of the draft. See Fig. 34. The length of the firebox also has some effect upon the draft; if it is long and has considerable volume the draft will be less with the same sized

exhaust nozzle than if made short. To obtain the best results, therefore, the length of the smoke box should be proportioned to the size of the exhaust nozzle.

THE CROWN SHEET.

- 92 The crown sheet, which is the sheet immediately above the fire, slopes toward the rear in some boilers and in others is made straight. The object aimed at in the sloping crown sheet is to prevent it from going dry in ascending or descending hills. Since this part is exposed to the highest temperature in the boiler it is important that it be kept covered with water at all times.

FLUE SHEETS.

- 93 Flue sheets are the thickest sheets in traction engine boilers, a condition made necessary in order to give sufficient holding surface for the flues. The usual thickness of plates used at the present time is about $\frac{1}{2}$ inch. While thin plates allow the heat to pass through more readily, the fact that much thicker plates are successfully used in other types of boilers, where pressures equally as high are carried, seems to be evidence that plates of this thickness are permissible. The holes for the flues should be drilled and reamed exactly to the required size. The truer the hole is made and the smoother the edges of both it and the surface of the flue, the better will be the joint between the two.

BOILER FLUES.

94 Boiler flues are made of either wrought iron or steel. Until within very recent years lap welded charcoal iron was usually specified but at the present time solid drawn steel tubes, i. e., tubes having no weld, are used almost exclusively for the traction engine trade. These tubes are made of a very soft grade of steel and are drawn almost exactly to size. They are much more uniform in size and shape than iron tubes, less liable to split, and much smoother on the outside, consequently scale does not adhere to them as much as it would to rougher iron tubes.

95 Table I gives the leading dimensions of boiler tubes from $1\frac{1}{2}$ inch up to $3\frac{1}{2}$ inches in diameter. Columns 5 and 6 gives both the bursting and collapsing pressures of lap welded wrought iron flues. Solid drawn steel flues will stand somewhat higher pressures than those specified for the wrought iron. The safe working pressures of these flues will be (if we use a factor of safety of 5) one-fifth of the values given in the table for bursting pressure. The size of boiler flues used for traction engines varies from $1\frac{3}{4}$ to as high as 3 inches in diameter, with probably the greater number around 2 or $2\frac{1}{2}$ inches.

96 During the past few years efforts have been made by the manufacturers to build boilers having a large amount of heating surface with as small a shell as possible. In order to attain this object small sized flues were used. It can easily be shown that the smaller the diameter of the flues used to fill a given sectional area, the greater will be the area of heating surface obtainable. The practical limit to

the smallness of tubes used depends upon the amount they retard the circulation of water in the boiler, and the difficulty of keeping them clean. It must be remembered that proper circulation in a boiler is just as necessary a condition in order for it to generate steam as is a large amount of heating surface.

TABLE I.

97 STANDARD SIZE OF BOILER TUBES.

Diameter in Inches	Thickness in Inches	Wire Gage No.	Length of the Tube per sq. ft. of Int. Surf.	Bursting Pressure	Collapsing Pressure
$1\frac{1}{2}$	.073	15	2.853	6200	5200
$1\frac{3}{4}$	.095	13	2.448	5300	4300
2	.095	13	2.110	4500	3700
$2\frac{1}{4}$	.095	13	1.854	4600	3600
$2\frac{1}{2}$	.109	12	1.674	4500	3600
$2\frac{3}{4}$	.109	12	1.509	4300	3100
3	.109	12	1.373	4400	3000
$3\frac{1}{2}$	.120	11	1.172	4200	2700

ARRANGEMENTS OF THE FLUES.

98 The arrangement of the flues in a boiler is an important matter. They should be placed in both horizontal and vertical rows, as shown in (a) Fig. 39. When so placed any scale or sediment can fall directly to the bottom, where it may be washed out. In the arrangement shown in (b)

where the flues are staggered in vertical rows, scale or sediment which falls from the top row of flues usually finds a lodging place on the one below. Moreover the circulation is not so good when the flues are so arranged. Experi-

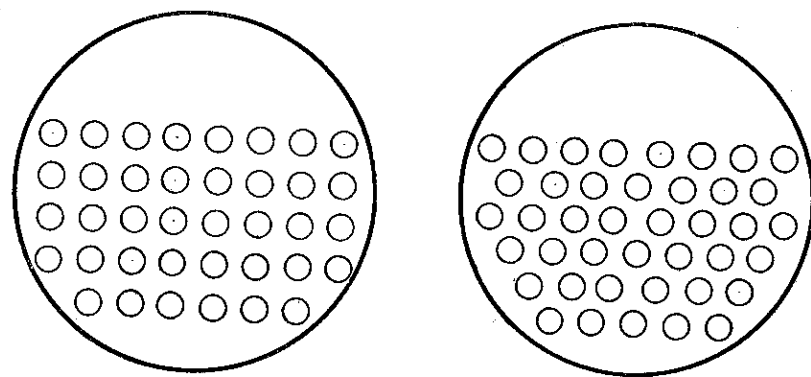


Fig. 39.

Arrangement of Flues in a Boiler.

ence has shown that boilers so equipped do not steam well in the field after they have been out a few weeks.

99 It may be justice to the manufacturers to state that so far as known the building of boilers with this arrangement of flues has been discontinued.

PUTTING IN FLUES.

100 Flues are either put in and beaded over, as shown in Fig. 40, or else simply expanded as shown in Fig. 41. When the latter method is used in traction engine boilers it is

customary to bead the firebox end of the tubes. The holding power of flues which are expanded without beading appears to be nearly equal to that of the beaded flue.

101 Some boiler makers use a copper ferrule between the flue and the flue sheet in the firebox end, an illustration of which appears in Fig. 42. Others depend upon a tight joint and do not use a ferrule. Where the tube sheet is carefully drilled and reamed to the exact size and the end of the flue turned in a lathe, so that absolutely clean surfaces come together and a perfect fit is secured, a joint can be made that is very hard to improve upon. Copper expands very much more than iron for the same difference in temperature, consequently when heated, the copper expands and fills the slight inequalities in the metal between flue and flue joint, making a perfect joint. This expansion of the copper accounts for the fact that boilers so equipped sometimes have leaky flues when cold but do not leak when warmed up.

TOOLS USED IN PUTTING IN FLUES.

102 There are two kinds of expanders in common use, viz.: the spring or sectional expander (Fig. 43) and the roller expander (Fig. 44). There is little choice between the two as both can be made to do good work. For repair work where the flue holes are slightly out of round, the sectional expander is preferable.

103 The sectional expander consists of a number of hardened steel segments, B, held together by a spring ring, S. A taper pin forces these segments outward and enlarges the head of the expander. The convex portion, D, forms the

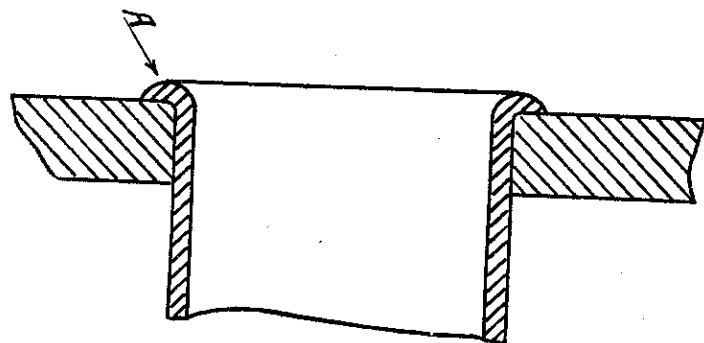


Fig. 40.
Beaded Flue.

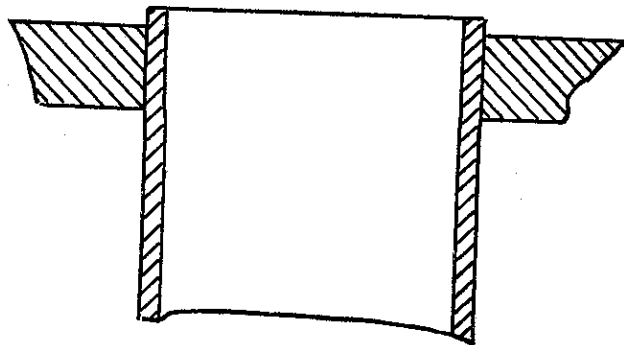


Fig. 41.
Expanded Flue.

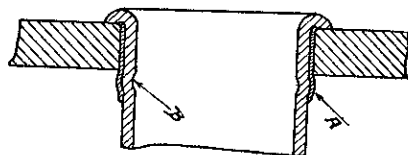


Fig. 42.
Flue with Copper Ferrule.

groove inside the tube sheet at B in Fig. 42. The concave portion, C, is the part that forms the joint between the flue and the flue sheet. In using this expander the taper pin is driven in tightly, then jarred loose, the expander turned slightly in the hole, and the operation repeated until the tube is expanded. After the tube is fully expanded any further use of the expander tends to stretch the flue sheet and may cause the adjacent flues to leak. These remarks hold true no matter which form of expander is used.

- 104 The roller expander consists of three or four rollers surrounding a taper pin and held in place by a cover plate shown in the drawing. A shield is also provided on the body of the expander which may be adjusted for the different thicknesses of flues. Especial care must be exercised in using this tool not to drive the rollers too deeply into the flue sheet. It is perfectly possible, in fact it frequently happens, that the flues are expanded so much that they are split.

BEADING FLUES.

- 105 A tool for beading flues is shown in Fig. 45. Sometimes a starting tool is used having a wider curve at A to start the bead, but more often this is done by first using the ball pene of a machinist's hammer and then finishing the job with a tool such as shown in the figure. The size of the curve at A is an important matter, for upon its size depends the size of the bead formed on the flue. If the bead is large the heat does not readily pass through into the water and consequently the end of the flue becomes burned and a leaky

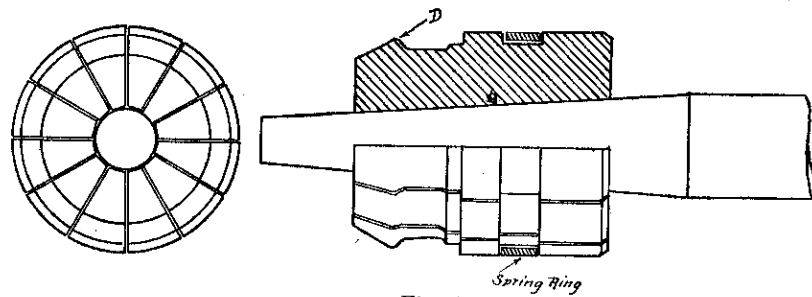


Fig. 43.

Spring Expander.

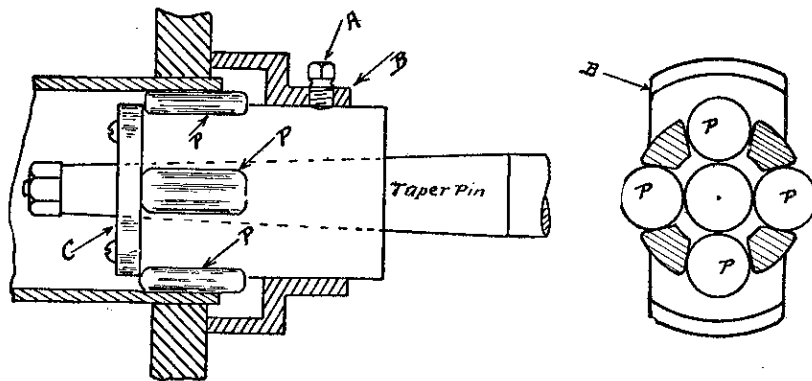


Fig. 44.

Roller Expander.

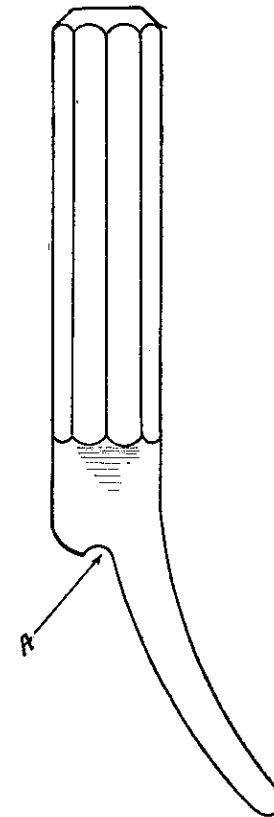


Fig. 45. Beading Tool.

flue results. The bead, especially in the firebox end, should be made as small as possible. When so made there is very

little tendency for them to burn off and the difficulty illustrated in Fig. 46 is avoided. Fig 46 illustrates how the forming of the large bead has drawn the flue away from the sheet leaving a space shown at B. Such a flue will leak in a short time after being put in.

DIRECTIONS FOR PUTTING IN FLUES.

- 106 1. Measure for each flue separately as the sheets may be bulged so that different lengths of flues are needed. Allow from $\frac{1}{8}$ to $\frac{3}{16}$ of an inch on each end for beading.

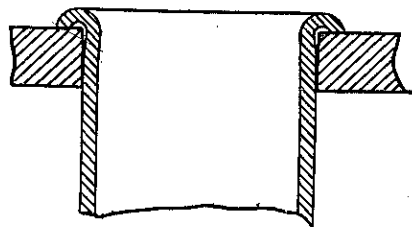


Fig. 46.

Example of Too Large Bead.

- 107 2. Anneal the ends of the flues. To do this, heat to a cherry red, and then cool slowly in slaked lime, sand or ashes. Slaked lime is best.
- 108 3. Clean the hole in the flue sheet, and clean all the rust from the end of the flue.
- 109 4. Place the flue in position and then expand; to do this, place the expander in the flue with the shoulder of the tool up tight against it. With a light hammer drive the taper

pin in lightly, jar it loose, turn it slightly in the flue, and repeat the operation until the flue is expanded all around and fits the hole tightly. Be careful not to drive the expander in at any time hard enough to split the flue or injure the flue sheet.

- 110 5. After expanding, bead the flue with the beading tool shown in Fig. 45.
- 111 6. After beading, use the expander again lightly to insure a perfectly tight joint.
- 112 7. Be careful to keep the guide of the beading tool up tight against the inside of the flue, so that the sharp point A, Fig. 45, will not groove the sheet.

TOOLS FOR REMOVING FLUES.

- 113 Flues sometimes have to be cut out in the case of repairs. In a well equipped boiler shop a rotary flue cutter is used which cuts the tubes without leaving any jagged edges, but



Fig. 47.

Tool for Removing Flues.

in the field an elaborate tool of this sort is seldom carried. A tool usually used for field work is illustrated in Fig. 47. The cutting edge is made about $\frac{1}{8}$ of an inch in width and the method of operation is to slit the tube back 2 or 3 inches at each end, then pinch it together, and withdraw it from the boiler. Or, it may be cut off, and removed through a

handhole, if so located that this can be done. Care must be taken if the flue has to be slit, as it must be if it is an inner one, not to injure the flue sheet.

DETACHABLE FLUES.

114 Within the past two or three years, there has appeared on the market a form of boiler flue, shown in Fig. 48.

115 The firebox end of this flue is flanged slightly and the front end is threaded. The tube is inserted from the firebox end and driven lightly into place. The tapered end makes a tight joint in the rear flue sheet. A brass nut shown at the right in the figure screws on to the end of the flue in the smoke box end. This nut is slightly tapered and when screwed into position draws itself tightly into the front flue sheet. Tubes put in in this way do not need either beading or expanding and can be taken out or put in in a very short time.

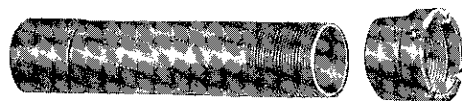


Fig. 48.

A Detachable Boiler Flue.

QUESTIONS.

1. How is the strength of a riveted joint expressed?
2. What is the strength in per-cent of a single riveted lap joint, (b) of a double riveted lap joint?
3. What is meant by "pitch" of the rivets?
4. What is the object of calking a boiler?
5. How are boiler heads braced?
6. Upon what is the strength of a cylinder subjected to internal pressure dependent?
7. What is the effect upon a cylinder subjected to internal pressure of increasing its diameter?
8. Why are longitudinal seams double riveted and transverse seams only single riveted?
9. State a rule for finding the bursting pressures of cylinders subjected to internal pressure.
10. What is meant by the term "Factor of Safety"?
11. Give a rule for finding the safe working pressure of a plain cylindrical boiler.
12. How do you figure the safe working pressure in a cylindrical boiler 30 inches in diameter and made of $\frac{1}{4}$ inch steel plate?
13. How do you figure the safe working pressure on the walls of the firebox?
14. What is the object of the dome, (b) of the dry trough?

CLARKE SCHOOL OF TRACTION ENGINEERING

15. Why is steam containing water objectionable in an engine?
16. What precaution should be taken with steam pipes placed inside of the boiler?
17. Describe the action of the arch used in fireboxes.
18. Describe the Buchanan firebox.
19. Describe the Abell firebox.
20. Why are crown sheets sometimes made sloping?
21. How is the size of boiler tubes designated?
22. How should flues be arranged in a boiler?
23. Describe two methods of putting in flues.
24. How is the joint between a flue and flue sheet made?

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LESSON WITH QUESTIONS

BOILER FITTINGS
PART III

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(By Correspondence)

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3. Before answering the questions carefully review the entire subject.
4. In answering do not write the questions—merely use their numbers.
5. Answers **MUST** be written on good white paper, in ink, and only on one side of the sheet.
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PART III.

BOILER FITTINGS.

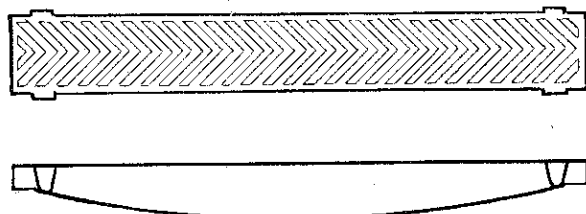
1. *Fire Box Fittings.*—The fire box fittings include the grates, dead plate, fire door, draft doors, straw chute, and all the other attachments that make up the equipment of the fire box.
2. *Grates.*—The grates used for coal burning are usually just plain bars placed side by side in the furnaces (see Fig. 49) or else grates made like the one shown in Fig. 50,



A Plain Grate Bar. Fig. 49.

known as the *herringbone grate*. The latter was designed to overcome the tendency to warp and twist, which is a fault of the plain bar. When straw is used for fuel all but two or three of the grates are removed and only

enough are left to keep the straw from falling into the ash-pan.



Herringbone Grate Bar. Fig. 50.

- 3 Regular straw grates consisting of fingers extending back two-thirds of the way across the firebox are sometimes used. These grates are quite convenient as the hard clinker formed in burning straw can be easily pushed back into the ash-pan and raked out.
- 4 *Rocking Grates.*—Rocking grates are to be preferred for plowing or freighting engines that burn coal. The grate bars in this kind of grate are supported on pivots and connected together by means of jointed links. A lever on the platform communicates with these links and enables the fireman to clean or dump his fire without having to stop the engine or open the fire door. The inrush of cold air incident to opening the fire doors is thus avoided, together with the consequent chilling of flues, which is the principal cause of their leaking.
- 5 *The Ash-Pan.*—In open firebox boilers a sheet steel ash-pan is suspended below the grates; in the closed bottom boiler the ash-pan is a part of the firebox itself. All boilers

should be equipped with a sheet metal extension pan into which the ashes may be raked and thoroughly wet down before being dumped. In this way much danger from fire is avoided.

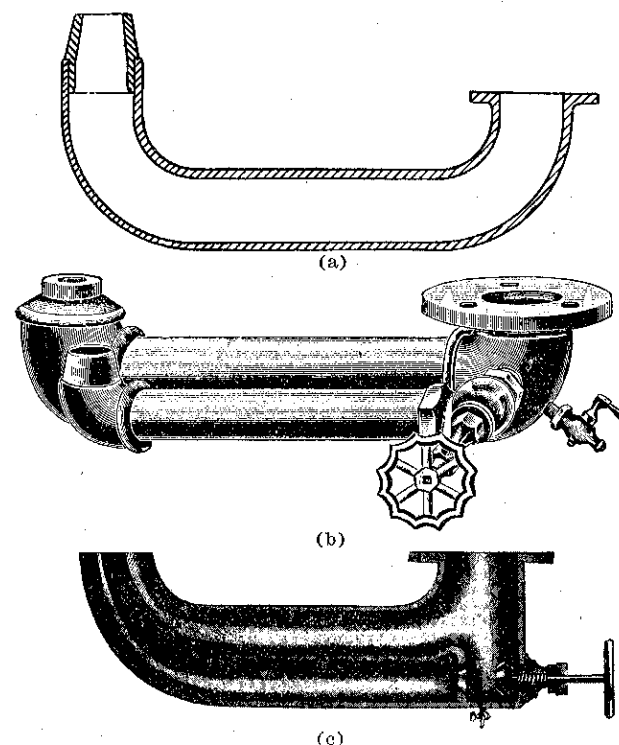
- 6 *The Dead Plate.*—The dead plate is a flat piece of casting usually about one foot wide, placed at the ends of the grates as illustrated in Fig. 4. It causes the fire to be placed well toward the forward end of the firebox and influences the direction of the draft.
- 7 *The Straw Chute.*—The straw chute is a casting put on over the fire door opening in place of a door when straw is used for fuel. A swinging sheet iron damper closes the chute when it is not filled with straw, thus preventing the ingress of cold air. Fig. 4 shows a straw chute in position. The fingers R prevent straw from being drawn by the strong draft over the brick arch.
- 8 *Doors.*—The fire door and other doors exposed to the high temperature of the firebox are provided with an inner wrought iron lining placed at a distance of an inch or two from the outer door. This lining protects the door casting from the heat. All doors should shut tightly so that the admission of air is absolutely under control. A leak of air into the smoke box impairs the draft and a leak at the draft doors makes it impossible to control the fire and, consequently, to control the steam pressure.
- 9 *Exhaust Nozzle.*—The exhaust nozzle is made in two styles, one with a bushing screwed in the end of the nozzle, and the other, with one or more openings which may be opened or closed from the outside called a *variable exhaust*

nozzle. The size and shape of the opening and the position of the nozzle at the base of the stack influences very greatly the intensity of the draft and consequently the steaming ability of the boiler. The form and size and the placing of the nozzle, therefore, becomes a matter of vital importance in the traction engine.

10 Since different kinds of fuel require different intensities of draft it follows that different nozzles must be used. With the first mentioned nozzle three bushings usually are provided, one large one, one intermediate, and one small one. These are marked respectively wood, coal, and straw; the large one is used when wood is burned, the intermediate when burning coal, and the small sized one for burning straw. Straw requires a more intense draft than either wood or coal and therefore demands the small sized nozzle. When a variable exhaust nozzle is used the amount of draft is regulated by the position of a lever or valve operated from the outside. This operates a valve in the nozzle which makes the opening either larger or smaller for the different kinds of fuel.

11 *Kinds of Exhaust Nozzles.*—Fig. 51 represents three kinds of exhaust nozzles, (a) is an ordinary nozzle with bushing, while (b) and (c) are variable or relief exhaust nozzles, having an auxiliary opening, closed by a valve, through which steam may escape. The amount this valve is opened regulates the intensity of the draft and the amount of back pressure on the engine. It should be opened as wide as possible and still have sufficient draft, for the more the exhaust is throttled, the more back pressure there is on the engine.

12 These nozzles are of considerable advantage where the fuel is good and little draft is needed to keep up steam, as

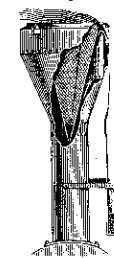


Exhaust Nozzles. Fig. 51.

is the case when working with a light load, or when burning a good grade of coal.

- 13 *Position of the Exhaust Nozzle.*—The exhaust nozzle should be placed exactly in the middle of the base of the chimney and should point directly up the center. If it should be tilted to one side the jet of steam will strike the side of the stack and part of it will be deflected down the chimney, thus defeating the very object at which it is aimed. It frequently happens that the nozzle becomes shaken loose, or misplaced in some way and the engine does not steam well.
- 14 A good rule to follow when any trouble is experienced from bad steaming is to look to the exhaust nozzle first, see if the right bushing is in, see if it is pointed up the chimney as it should be, and see that it is free from scale.
- 15 *The Action of the Exhaust Nozzle.*—The action of the nozzle is simple. When a jet of steam passes out of the nozzle at a high velocity it induces the air in the bottom of the stack to move in the same direction as itself, thus causing a partial vacuum at this point. Air from the smoke box rushes in the same direction, causing a partial vacuum in the smoke box also. This vacuum is greatest in the base of the stack and a little less in the smoke box and still smaller toward the upper portions of the stack or chimney. The vacuum in the smoke box and chimney causes a rush of air through the firebox and flues and so causes a heavy draft.
- 16 *The Blower.*—The blower is a small pipe leading from the steam space in the boiler to the base of the stack where it serves the same purpose as the exhaust nozzle when the engine is not running. It is not advisable to turn the

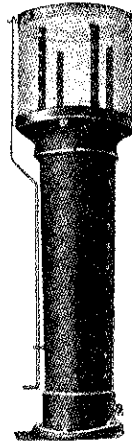
- blower on until a pressure of at least 20 pounds appears on the gauge, as enough steam will be lost in this way to more than off-set the gain from additional draft.
- 17 *Spark Arresters.*—The South Bend spark arrester illustrated in Fig. 52 is used on a good many traction engines. It consists of a conical wire screen inverted in the top of the chimney and fitted in many machines with a rod running down the outside of the chimney for raising and lowering it. Cinders passing up the chimney are deflected



South Bend Spark Arrester. Fig. 52.

- by the wires of the screen into a trough at the top of the stack which communicates with a tube on the outside into which the cinders fall and from which they may be removed through a door at the bottom. Only fine cinders can pass through the screen because in order to do so they must turn a right angle in order to get into the cone and another before they can pass out into the air. The heaviest cinders are deflected back into the smoke box.
- 18 Another kind of spark arrester is shown in Fig. 53. In this device a wire hood is placed over the top of the stack having either a fine wire cover or sheet metal cover on top

which may be opened when starting the fire. The principle of action in this case is the same as in the arrester just described, that is, the cinders in order to escape must turn

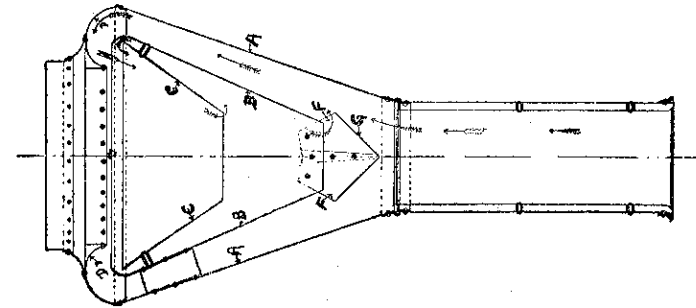


Spark Arrester. Fig. 53.

a square angle in order to pass out through the side of the screen. This they can not do, because, owing to their weight and momentum, they can travel only in straight lines, and so strike the top of the arrester and are either deflected back into the smoke box or else held imprisoned in an atmosphere containing very little oxygen where their fire is soon quenched, until pulverized sufficiently by striking the arrester to pass through into the air.

- 19 In Fig. 54 the cinders pass between the inner cone B, and the outer shell A, until they meet the curved deflector

D, which throws them back, if they are heavy enough, into the central space, where they are again caught by the hot gases as they pass through the openings F, and whirled around through the same cycle until they are broken up finely enough to escape with the smoke at the top.



Spark Arrester. Fig. 54.

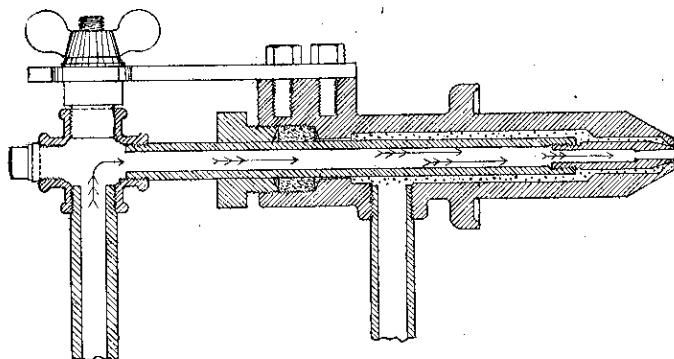
- 20 Other spark arresters are provided with a trough or other receptacle containing water which is supposed to catch and quench the heavier cinders.
- 21 Engines which exhaust up the smoke stack and which burn either wood or straw need an arrester to prevent danger from fires. Coal burners do not need them so much because the cinders are heavier and unless the engine is working very hard it seldom throws live sparks.
- 22 *Care of Spark Arresters.*—In starting the fire it is necessary to lift the spark arrester out of the way, or open it in some manner, in order to provide an uninterrupted draft. If this is not done it will take a long time to get up steam. The meshes of the screen become filled with soot after being

used a day or two and should be cleaned out frequently with an old broom. Occasionally it is necessary, in burning some sorts of straw, to take the conical screen out altogether in order to get enough draft, and either leave it out altogether or turn it bottom upwards on top of the stack.

23 When an engine does not steam easily the spark arrester is the second place to look for trouble.

24 *Oil Burning Attachments.*—In certain sections of the country where oil is used for fuel the firebox must be fitted up differently than for coal, wood, or straw and an especial form of oil burner must be provided.

25 Fig. 55 represents a simple style of oil burner used in a well known make of traction engine. Oil is supplied by



Oil Burner Nozzle. Fig. 55.

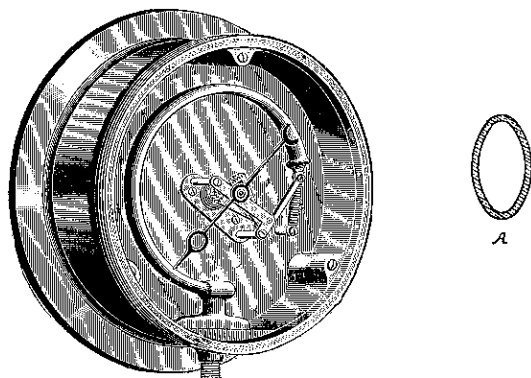
means of gravity pressure from a tank on the top of the boiler; the flow being regulated by means of a valve in the supply pipe.

26 The object of oil burners is to atomize the oil and mix it with the proper amount of atmospheric air to insure perfect combustion. In the type of burner illustrated, the atomizing is accomplished by means of a jet of steam which is supplied through a separate steam pipe from the boiler; the air is supplied through the usual draft doors. A fire brick target is provided for the oil jet to strike against and frequently a fire brick lining is provided in that part of the firebox where the heat is most intense. When the brick is heated to incandescence it turns the oil into the gaseous form, which is the form it must exist in, in order to burn to the best advantage. Sometimes a jet is directed upon a fire brick target in the back of the boiler, sometimes the jet is directed in the opposite direction. In a well designed oil burning boiler the whole interior of the firebox is filled with the flame of the burning oil. A further discussion of this subject will be taken up under the head of "Combustion" in Part V.

27 *Safety Devices.*—The safety devices with which most traction engine boilers are provided are as follows: The steam gauge, safety or pop valve, water glass, try cocks, and fusible or soft plug. All of these devices, except the try cocks, are automatic or partly automatic and when in working order add very much to the safety of the boiler.

28 *The Steam Gauge.*—The steam gauge indicates the steam pressure in the boiler in pounds per square inch above atmospheric pressure. For example: 150 pounds pressure on the gauge means that on each square inch on the inside surface of the boiler shell there is an outward steam pressure equal to 150 pounds.

- 29 The most common form of gauge used is known as the Bourdon spring gauge, a cut of which appears in Fig. 56.



Single Bourdon Spring Gauge. Fig. 56.

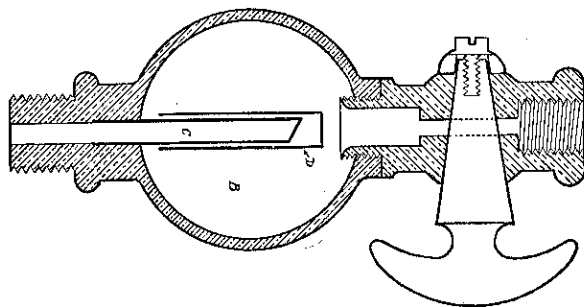
It consists of a hollow brass spring, elliptical in section, as shown at A in the cut, closed at the upper end, and connected to the steam space in the boiler at the other. The free end of this spring is connected by means of a link, to a segment lever, which meshes with a small pinion on whose axis a pointer is fastened. When pressure is exerted on the inside of the tube it tends to become circular in section and to straighten out. The distance which the free end moves is proportional to the steam pressure. This motion is transmitted by means of the link, lever, segment, and pinion to a pointer which moves over the face of a dial on which is recorded the pressures corresponding to

different positions of the index. The back lash of the pointer is taken up by a hair-spring attached to the shaft just below the small pinion. The parts of a steam gauge are very delicate and should not be tampered with.

- 30 *Connections between Steam Gauge and Boiler.*—If steam were admitted directly into the Bourdon spring the gauge would not register correctly on account of expansion due to the high temperature to which the spring would be subjected. It is customary in stationary boilers to connect the gauge to the boiler by means of a circular loop of pipe; the lower part of this loop will fill with water through condensation of the steam when the boiler cools. When the steam pressure is next applied it will push the plug of water up into the gauge and compress the air which always occupies the space in the upper end of the hollow spring. When a gauge is in operation then, the upper part of the Bourdon spring is filled with air and the lower part with a plug of water, which is held in place by the steam pressure in the boiler. The water and the air are at a lower temperature than the steam and protect the spring from excessive temperatures. In traction engine work a coil of pipe could not be used on account of the vibrations to which it would be subjected on the road.

- 31 *The Syphon.*—Fig. 57 is a sectional view of a syphon such as is used to form the connection between the boiler and the steam gauge on traction engines. It consists of a brass bulb B, having a central pipe C, extending well up into the central chamber. A cap D, fits loosely over this tube and deflects the steam toward the bottom of the cham-

ber where it condenses and is then forced up into the spring of the gauge. When the boiler cools down, water flows from the gauge up inside of cap D, and then down the cen-



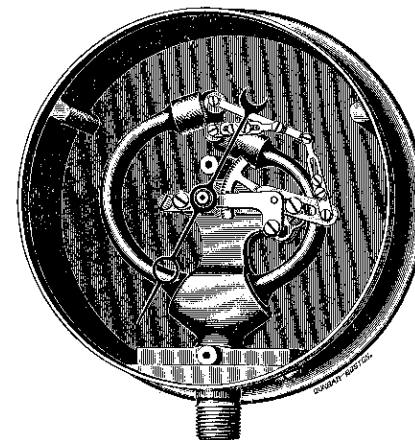
Steam Gauge Syphon. Fig. 57.

tral tube into the boiler, thus preventing any damage to the gauge through frost. The cap D, together with the central tube, forms a syphon in which the cap D forms the short leg and the central tube the long leg. It drains the gauge in just the same way as a syphon made of a piece of hose drains the water out of a barrel.

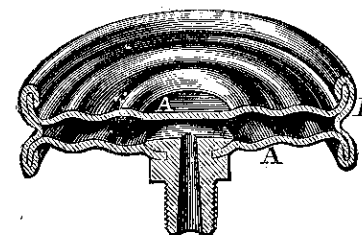
Double Spring Steam Gauges.—A gauge of this kind is shown in Fig. 58. For some kinds of work it is said to be more durable than a single spring gauge, and less subject to vibrations of the pointer in going over rough roads.

32 *The Utica Steam Gauge*, instead of being fitted with a Bourdon spring, is provided with what is known as a capsular spring which is clearly illustrated in the accompanying illustration, Fig. 59, and also in Fig. 60, which latter cut

also shows the whole internal mechanism of the gauge with its series of multiplying levers which transmits motion



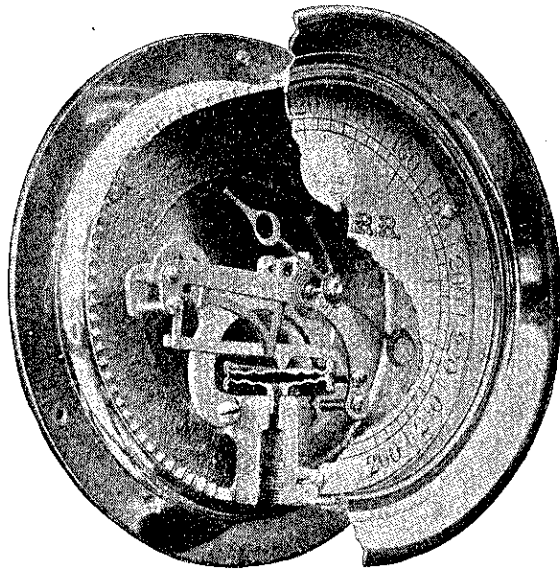
Double Bourdon Spring Gage. Fig. 58.



Capsular Spring. Fig. 59.

from the flexible capsule to the hand which rotates over the face of the dial.

- 33 When steam is admitted to the gauge the thin walls of the capsule A spread apart a distance proportional to the pressure applied within them, and while this distance is



Utica Steam Gauge. Fig 60.

- not very great it is sufficient, with the series of levers used, to give enough motion to the hand.
- 34 Both the Bourdon spring gauge and the capsular spring gauge have been in use for a great many years, and both have proved to be efficient in actual service. The latter was brought out in its present form in the year 1865, super-

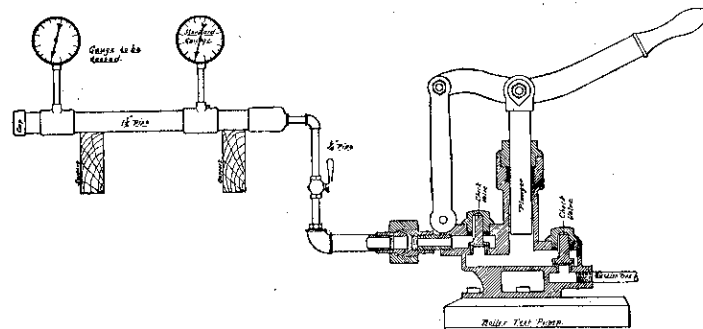
- seeding what was known as the diaphragm gauge, that is, a gauge having only one pressure plate instead of a capsule. Both the Bourdon spring and the diaphragm spring made their first appearance somewhere about the year 1850.
- 35 *Adjustments for a Bourdon Spring Gauge.*—If the hand moves either too slow or too fast, all that is necessary to do is to loosen the screw that holds the adjusting strap and by sliding this strap backward or forward the hand may be made to travel either faster or slower as the needs of the case demand. The adjusting strap, by the way, is the strap which makes the connection between the Bourdon spring and the toothed segment which rotates the pinion.
- 36 It is not necessary usually to oil the movement of a steam gauge, but whenever it is necessary use only the best clock oil, and that only sparingly. Ordinary oil thickens and gums and will prevent the best gauge from working.
- 37 Bourdon springs occasionally split or crack on the edges, and the first thought usually of a repair man is to solder them. This, however, should never be done for two reasons: first, the temper of the spring is changed, and second, the solder deadens the elasticity of the spring.
- 38 *Adjustments for a Capsular Spring Gauge.*—In order to make the hand move faster over the first part of the circle, it is necessary to bend the left end of the long lever which extends across the face of the spring downward. Bending the same end of the lever upward will cause the hand to travel faster over the last part of the circle.
- 39 If it is desired to make the gauge register less through the whole circle all that is necessary to do is to move the

tongue of the toothed sector toward the left; the opposite result can be attained by moving the tongue of the sector to the right. In both cases the gauge faces the operator.

- 40 *Testing and Repairing Gauges.*—The gauges used for traction engine purposes are high pressure gauges, that is, they register up to about 200 pounds. Up to 25 or 30 pounds they are not supposed to be accurate and rarely are, but above 30 pounds they should not vary from the actual pressures more than a fraction of a pound one way or the other.

- 41 For recording low pressures, what is known as a low pressure gauge is needed. This will register all pressures correctly from zero to 30 or 40 pounds.

- 42 At the beginning of the season the steam gauge should be tested, since the safety of the boiler depends largely upon its accuracy. If the gauge does not agree with the pop-valve it is reasonable to suppose the fault lies with the



Gage Testing Device. Fig. 61.

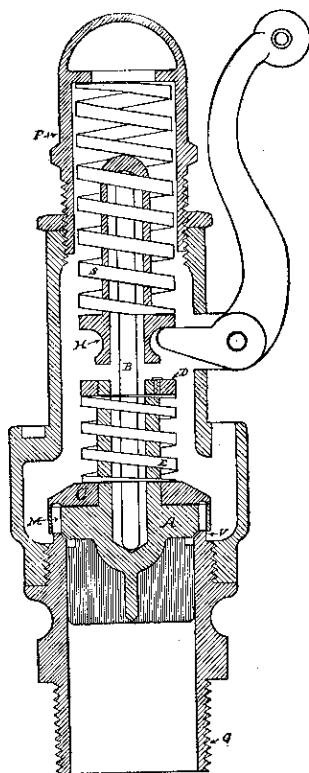
gauge. In any event, no time should be lost to determine which is at fault and set one or both of them right.

- 43 There are a number of good gauge testing sets on the market, but most of them are quite expensive. If one has a boiler testing pump, however, he can easily make a gauge tester with pipe fittings that will answer the purpose fully as well as the more expensive ones. A gauge tester of this kind is illustrated in Fig. 6 and perhaps requires no explanation more than to say that the standard gauge should be known to be accurate. Most steam gauges are adjusted properly when they leave the factory, but occasionally become deranged in shipment, consequently it is well to test even new gauges.

- 44 It frequently happens that the pointer slips on the shaft and will register 5 or 10 pounds wrong all the way along the scale, or it may even happen that the gauge will be incorrect, varying in both directions, due to a slippage of the hand. This fault is usually remedied by removing the pointer and running the pressure up to a known point, using a test gauge for this purpose and then replacing the hand. After this is done, the pressures should be applied to both the test gauge and the gauge being tested all the way up the scale and back again to ascertain if any serious variations are apparent.

- 45 *Spring Safety Devices.*—Every boiler should be equipped with a safety valve and those boilers which are used for road purposes, such as traction engines and locomotives, must be equipped with spring safety valves. The object of the safety valve is to relieve the pressure in the boiler auto-

matically at a certain point previously determined upon. If a boiler is generating steam faster than the engine can use it, it is evident that the pressure in the steam space will rise and if nothing is done to relieve this pressure an



Crane Pop Safety Valve. Fig. 62.

explosion is very liable to occur. It is the duty of the safety valve to prevent the increase of pressure beyond a certain amount.

46 Fig. 62 is a sectional view of a "Crane" pop-safety valve. The threaded portion G is screwed into the dome of the boiler, thus placing the interior of the valve in communication with the steam space of the boiler. It consists of a main valve A, beveled at an angle of 45 degrees, which is held to its seat by means of a stem B. This stem carries a cap at H which forms the lower support for the spring S. Between this flange at the bottom of cap H and the nut F a heavy spiral spring is inserted which may be compressed by screwing down the nut F, thus putting a load upon the main valve. When the steam pressure acting upwards on the valve equals the load occasioned by the spring, the valve is on the point of opening.

47 Just above the main valve the auxiliary valve C is located, which is held in position by means of another spiral spring, E, which in turn is held in compression by the nut D. This auxiliary valve regulates the amount of waste or loss of pressure between the opening and closing points. It is entirely independent of the main spring and valve, and when once properly set for the amount of waste required needs no more adjustment even though the load on the main valve be changed a considerable amount. For example, if the main valve is set to blow off say at 120 pounds and the auxiliary valve is set to waste 3 pounds, the escape of steam will cease when the pressure falls to 117 pounds, and the valve will not open again until the pressure reaches

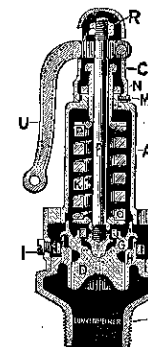
120 pounds. Or, if the main valve is set at 100 pounds, the action of the auxiliary valve will be the same as before, and the escape of steam will cease at 97 pounds.

- 48 The action of the pop-valve may be explained as follows: In all pop-valves a chamber must be provided in the main valve into which the steam may expand when the valve opens, thereby increasing the area against which the steam acts. The action of the steam impinging on this larger area creates a lifting force greater than the strength of the spring, thus holding the valve open until the pressure is relieved. There must also be means provided to relieve this pop chamber of its pressure in order that the valve may seat easily. Referring to the figure, M is the pop chamber which opens by means of holes or ports into an annular space provided in the lower part of the auxiliary valve. The force of the steam acting on the auxiliary valve at this point is sufficient to overcome the force of the light spring E, and allow the valve C, to lift from its seat and gradually relieve the pressure in the pop chamber M.

- 49 When valve A first opens, the steam suddenly expands against a large area in the pop chamber and throws the main valve wide open, but an instant later the auxiliary valve gradually opens and relieves this pressure, thus allowing the main valve to fall back to its seat when the pressure in the boiler falls. In other words, the auxiliary valve destroys the effect of the pop chamber, and consequently the amount of waste. The time required for it to do this depends upon the tension of the spring E.

- 50 Some makes of pop-valves are provided with regulating

screws, or a regulating wheel, by which the waste of steam may be regulated. Whenever the tension of the main spring is changed in these valves it is necessary to regulate the amount of waste.



Lunkenheimer Pop Valve. Fig. 63.

- 51 *The Lunkenheimer Pop Valve.*—Fig. 63 contains only one spring to hold the valve on its seat, the amount of waste being regulated by the regulating ring A. If the valve pops suddenly and does not relieve the pressure enough, ring A should be turned toward the left. If it allows too much loss of pressure it should be turned in the opposite direction. Whenever the tension or popping off point of the main valve is changed very much the amount of waste or loss of pressure should be regulated in the manner above described.
- 52 Spring safety valves are strongly made and will last a long while with little liability of getting out of order. The

point of blow off is regulated in all of them by means of a nut at the upper end of the valve. Screwing down the nut increases the tension, unscrewing it decreases the tension on the spring. One complete turn of the adjusting nut on almost all of these safety valves changes the pressure at which the valve will pop off from 25 to 30 pounds.

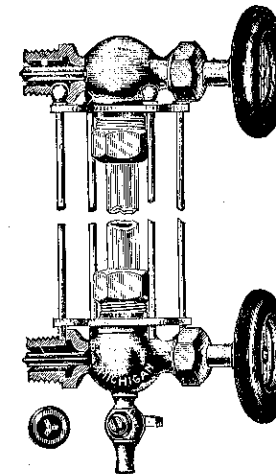
53 Safety valves are set at the proper point when they leave the factory. It is not advisable to increase the pressure on a boiler beyond that at which the pop valve is set by the manufacturer, since he usually sets the valve as high as he thinks it is safe to carry the pressure in the boiler.

54 *Directions for Taking Care of Safety Valves.*—The safety valve should be connected directly to the boiler without any pipes or elbows. Care should be taken in making joints with red lead to make sure that no lead gets on the valve seat; in fact, red lead should be used very sparingly, if at all, in making a joint. If for any reason the valve has to be taken apart, the tension on the spring should be readjusted on a gauge testing machine in connection with an accurate steam gauge. The lever on the side of the valve is used to open it by hand to make sure the valve is not stuck to its seat. In traction engine work this precaution is hardly necessary since the valve usually pops off several times every day any way, but in stationary work it is the duty of the fireman to lift the safety valve off its seat every morning.

55 The steam pressure in the boiler should be maintained as nearly constant as possible and at a point a little below that at which the safety valve acts. It is not an evidence

of a good engineer to hear the safety valve blow off every little while.

56 *The Glass Water Gauge.*—The gauge glass is a glass tube about one foot long, connected to the water space of the boiler at its lower end and to the steam space at its upper end by means of suitable brass connections provided with valves by which both steam and water may be shut off from the glass. A pet cock at the lower end provides



Gage Glass and Connections. Fig. 64.

means for draining the glass. The gauge on traction engine boilers is sometimes placed on the rear sheet of the water leg; sometimes on the side of the firebox; and sometimes on the side of the main shell. It makes little differ-

ence where it is placed, if it is located where it is in plain view of the engineer. When properly placed, water will cover the highest point of the crown sheet as long as it is visible in the glass.

- 57 *Determining the Position of the Gauge Glass.*—On taking charge of a new boiler the engineer should first determine how the glass is placed, so that he may be absolutely certain of the depth of the water over the crown sheet at all times. This may be done in the following manner. First level the boiler, then take out either the filling plug or the upper handhole plate in the back of the water leg and measure the depth of water over the crown sheet, noting at the same time the depth of water in the glass. Occasionally a mistake is made in locating the glass at the factory, making it necessary to carry the water either higher or lower in the glass than is customary. If the engineer acquaints himself with the way the glass is placed, on taking charge of a new engine, he will know exactly where to carry the water.

- 58 *Care of the Water Glass.*—The glass should be blown out at least once every day to make certain that no scale or sediment is lodged in the valves which connect it with the boiler. To do this, close the valve in the lower gauge connection, open the drip cock at the bottom of the glass and then open the upper or steam valve. These valve openings, by the way, are not much larger than a wheat straw, and if not watched will become closed with scale in a short time.

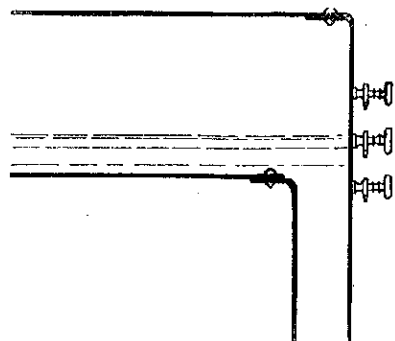
- 59 On going to the engine in the morning the attendant in

charge should first open both the upper and lower valve of the glass, or at least try them to make certain that they are open before building the fire. If the upper valve is closed and the lower valve is open, water will rise to the top of the glass, due to the pressure of the steam within the boiler. On leaving the engine at night both the upper and lower valve should be closed and the glass drained, especially in the colder sections of the country during the threshing season, otherwise the glass is apt to freeze and break.

- 60 In putting in a new glass it is necessary to make sure that both upper and lower sections are in line with each other, for if one is slightly twisted enough so that the glass bears against one side of the brass connection, the expansion of the glass is almost sure to cause breakage when steam is turned on. The gaskets which make the joint between the brasses and the glass are made of rubber and can be secured through the regular dealers or any of the supply houses. In cleaning a glass be careful not to scratch the inside of the tube with a metal point. A slight scratch on the inside of a glass tube is almost certain to start a crack. In case a glass breaks, close both the upper and lower valves and run with the gauge cocks until stopping time, or, if care is taken to warm up the glass, a new one may be put in immediately.

- 61 *The Try Cocks or Gauge Cocks.*—The try cocks or gauge cocks are more reliable than the gauge glass. Fig. 65 shows the general arrangement of gauge cocks in relation to the crown sheet and water space of the boiler. It is customary to provide a boiler with three cocks; one at the

highest position at which it is desired to maintain the water level and the lower one about an inch above the highest point of the crown sheet. The proper position to maintain the water level is about at the middle gauge cock. If water



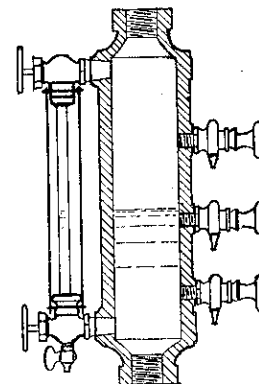
Position of Gauge Cocks. Fig. 65.

is carried too high, water will be carried over with the steam, and if too low, damage to the boiler is apt to occur. The gauge cocks should be tried frequently to make sure that they are in working order and to verify the position of the water in the glass.

62 *Water Columns.*—Water columns are used in some traction engines and on almost all stationary boilers. The object of the water column is to provide a connection for the gauge glass and try cocks where these accessories will not be affected by the violent ebullition at the surface of the water.

63 Fig. 66 represents a water column with try cocks, and water glass, and gauge glass attached. The readings of

both the gauge glass and try cocks are a little more reliable when placed on a water column than when attached directly to the boiler. The steam gauge is also frequently attached to the water column, and when so connected does not need the addition of a syphon, provided the gauge connection is made below the water level in the water column.



A Water Column. Fig. 66.

64 *The Fusible Plug.*—The fusible plug is located in the highest point of the crown sheet in fire box boilers, and in the combustion chamber, just above the top row of flues in return flue boilers. They are intended to prevent damage to the boiler due to low pressure. In many states they are required by law.

65 The ordinary styles of fusible plugs are shown in Fig. 67. They consist of a brass plug having an irregular opening through the center about $\frac{1}{4}$ of an inch in diameter at

the lower end. This opening is filled with a metal, usually pure tin, which has a low melting point. As long as the plug is covered with water this metal is kept from melting by the comparatively cool temperature of the water; but if the water level sinks, leaving the upper part of the plug uncovered, the metal quickly melts, allowing steam and water to rush through into the fire box, thus quenching the fire or



Fusible Plugs. Fig. 67.

at least giving warning to the engineer that the water is too low. The peculiar shape of the soft metal plug prevents the steam pressure from blowing it out.

- 66 *The Care of Fusible Plugs.*—When in good condition the fusible plug is a very reliable safety device, but like all other parts in a machine it requires careful attention to keep it in proper working order. If scale forms over the top of the plug, the metal may melt out and the steam be held back by the scale. Many instances are on record where this has happened. It is advisable then for the traction engineer to remove the fusible plug every time he cleans his boiler and make sure that it is not covered with a coating of scale. When screwed back in place the threads should be given a coat of graphite to keep them from sticking. Do not oil the threads as the oil will burn and make it very difficult to remove the plug next time. The plug

should be refilled with good Banca tin at the beginning of each season.

- 67 *Handholes and Cleanout Plugs.*—A number of handholes and cleanout plugs must be provided in every boiler. Their number and position depend upon the style of the boiler. In firebox boilers there should be a handhole in the smoke box end above the top row of flues and either a handhole or plug below the tubes. At the rear of the boiler a handhole should be provided in the water leg just above the crown sheet and one at each corner of the bottom of the water leg, if it is an open bottom or square bottom firebox. In the case of round bottom fire boxes the two handholes, one in front and one at the rear, situated at the lowest point of the curve, are usually considered enough, although it would probably be better if two more were placed either in front or behind at the point where the straight sides of the firebox meet the curved portion below. In any event, the purchaser of a traction engine, before accepting the engine, should go over it carefully to make certain that all the handholes are provided which are needed to clean it properly. The life of a traction boiler depends largely upon how well it is kept clean, and this can only be accomplished by having the proper means for cleaning provided.

- 68 *A handhole plate* consists of a flat piece of cast iron held against the inner surface of the bottom plate by means of a bolt which passes through its center and through a cast iron spider on the outside of the boiler. Some sort of gasket or packing must be placed between the cover plate

and the boiler shell. The material used is sometimes sheet lead, rubber packing, tubular packing, or brown paper. The latter is usually the easiest to get and if put on properly answers the purpose as well as anything else.

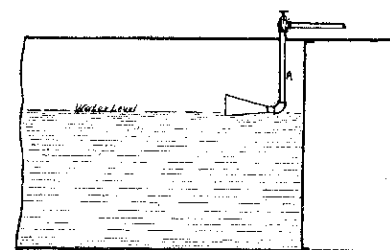
69 In putting in handhole plates after the boiler has been cleaned, care must be taken to remove all particles of burnt packing from the inside of the boiler against which the plate rests, and also from the surface of the cover plate itself. If a little graphite is rubbed on both sides of the gasket before it is put in place, it will not stick to the plate and will be easily removed next time. Gaskets made of sheet lead can be used several times, if care is taken in removing them to put them back in exactly the same position they occupied before. After steam has begun to form it is necessary to tighten the nut holding the handhole plate in position, because the expansion of the bolt, due to the change in temperature in the boiler, is sufficient to loosen the tension on the nut, and unless tightened again the packing is liable to blow out.

70 *Blow-Off Valves.*—There are two kinds of blow-off valves, viz., surface blow-off valves and bottom blow-off valves. All boilers are provided with a bottom blow-off valve, located at the lowest point in the boiler. Any ordinary valve may be used for this purpose, but the best is a valve having a straight opening. A water cock answers the purpose as well as anything that can be used. The trouble with globe valves, or any valve that lifts from its seat, is that scale or sediment may stick on the valve seat and prevent it from seating tightly. The bottom blow-off

BOILER FITTINGS.

is used to let the water out of the boiler or to blow off any required amount of water. In traction engine work it is used, or should be used, frequently, to remove sediment that accumulates in the bottom of the boiler or to reduce the percentage of alkali salts in the water. A further discussion of this will be taken up in Part IV under the head of "Feed Water."

71 *Surface Blow-Off Valves.*—This piece of apparatus is shown in Fig. 68. It consists of a flattened cone of sheet

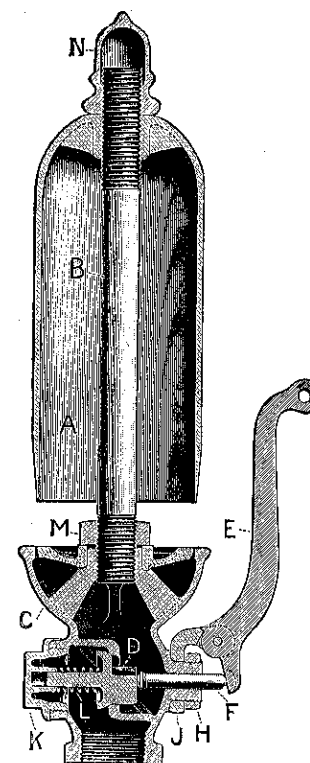


Pipe A comes out at side of boiler instead of at top as shown above

A Surface Blow-Off. Fig. 68.

metal extending nearly across the boiler and so located that when the valve A is opened, the rush of steam to the outlet will carry with it any scum or impurities resting on the surface of the water. Water that is taken from sloughs or coulees containing considerable decayed vegetable matter causes more or less foaming in a boiler on account of the scum which rises to the surface. If this scum can be removed in some way, as, e. g., through the surface blow out, it prevents a great deal of the difficulty experienced through foaming.

- 72 A surface blow-off is a valuable addition to any boiler operating in those parts of the country where the water is rather alkaline and is obtained mostly from ponds or sloughs. Whenever either of the blow-off valves are opened, with the boiler under steam pressure, it is the duty of the engineer to stay right by them until they are again closed.
- 73 *The Whistle.*—The whistle is used for signaling purposes. A uniform code of signals should be adopted and should be strictly adhered to. While there is no code that is universally used, probably the one given below, with some modifications, is the one most generally in use:
- 74 One short blast while working means that the engine will be shut down.
- 75 Two short blasts is the signal to start up again.
- 76 One long blast, followed by three short ones, is a signal to the water man to hurry.
- 77 Three short blasts is a signal to the bundle teams that grain is needed.
- 78 One long blast in the morning indicates the position of the machine, and,
- 79 Two long blasts in the evening is a signal that the job is completed or that the work of the day is done.
- 80 Fig. 69 is an illustration of a steam whistle. It consists of a base attached to the boiler having a valve which is operated by means of a lever. When the lever is pulled over, steam escapes around the edge of the flaring mouth of the body of the valve. As the steam rushes upward it compresses the air and steam in the bell; the air being



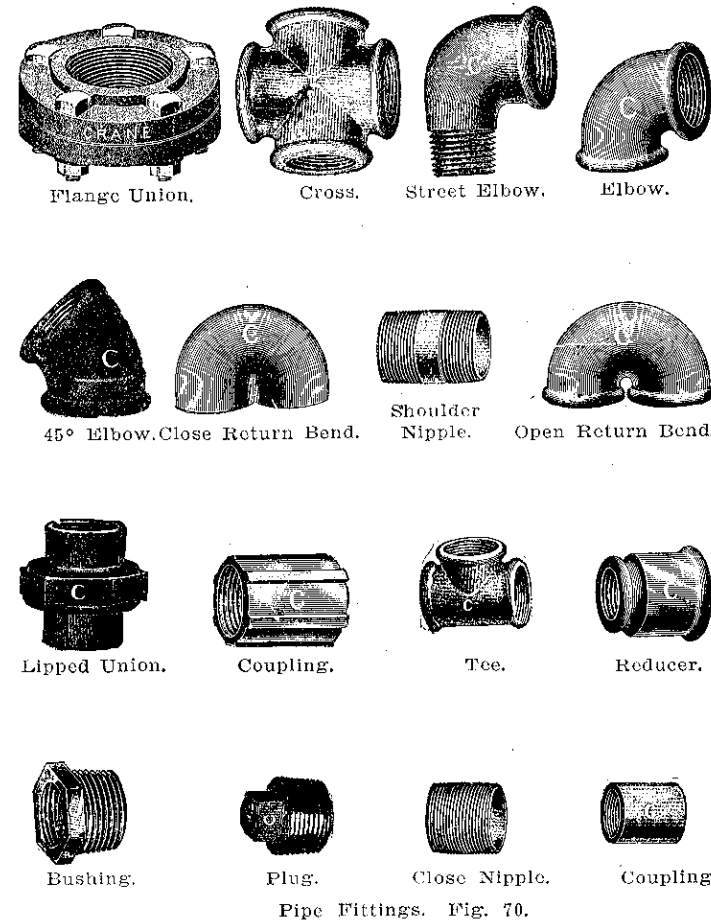
Whistle. Fig. 69.

elastic springs back and is kept in constant vibration by the escaping steam. It is this vibration which is transmitted to the surrounding air that causes the sound. The tone of the whistle can be changed by shifting the bell up or down

on the stem which supports it. Screwing it down makes the sound shriller, screwing it up produces a deeper note. Some steam whistles are made having a bell in three compartments, each of different size. Such whistles will produce three distinct notes which produce a rather pleasing effect if the tones chord perfectly. If the whistle valve gets stuck open the whistling may be stopped by filling the bell with cotton waste, which can be poked in with a long stick.

81 *Pipes and Pipe Fittings.*—The pipes used for steam purposes are made of lap welded wrought iron. The size of flues is designated according to the outside diameter, i. e., a 2-inch flue is 2 inches in diameter on the outside. Steam pipes and water pipes are measured internally, i. e., a 2-inch steam pipe is 2 inches in diameter inside or nearly that. The actual sizes of pipes vary somewhat from the dimensions specified.

82 Fig. 70 represents the pipe fittings in common use. It is well for the student to examine this cut carefully and learn their names so that he may be able to specify exactly what he wants in case it is necessary to order any repairs. Table No. I gives the sizes of steam, gas, and water pipe that is ordinarily carried in stock. Sizes different from those in the table can only be obtained on special order.



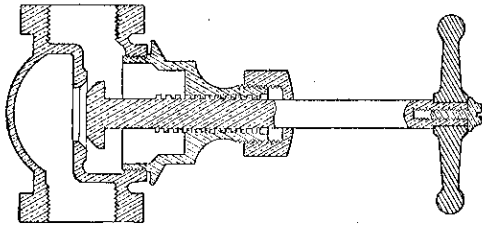
83 TABLE II.
DIMENSIONS OF STANDARD PIPE FOR GAS, STEAM AND
WATER.

Nominal Size Inside Diameter in Inches	Actual Outside Diameter in Inches	Thickness of Walls of Pipe in Inches	Number of Threads per Inch of Screw
Bolt Welded	$\frac{1}{8}$	.40	.068
	$\frac{1}{4}$	.54	.088
	$\frac{3}{8}$	.67	.091
	$\frac{1}{2}$	.84	.109
	$\frac{3}{4}$	1.05	.113
	1	1.31	.134
	1 $\frac{1}{4}$	1.66	.140
Lap Welded	1 $\frac{1}{2}$	1.9	.145
	2	2.37	.154
	2 $\frac{1}{2}$	2.87	.204
	3	3.5	.217
	3 $\frac{1}{2}$	4	.226

- 84 *Pipe Fitting.*—Pipes are usually connected by means of couplings or unions. If the pipe can be screwed together from one end continuously, couplings are preferable. Frequently, however, this cannot be done, owing to the necessity of joining pipes whose ends are fastened. In this case a union must be used. Lipped unions are employed for small pipe and flanged unions for pipe above 2 $\frac{1}{2}$ inches in diameter.

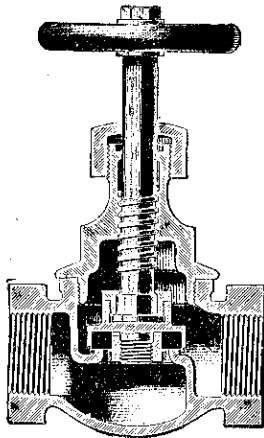
- 85 Pipe threads are cut with pipe taps and dies. Ordinary machinists' or blacksmiths' taps and dies will not do at all for pipe threads. In order to make a good pipe thread, the taps and dies must be sharp so as to cut a clean thread.
- 86 In threading a piece of pipe the die should be turned on until the pipe just reaches flush with its outer surface. This is necessary because the die cuts a tapered thread having a taper of $\frac{3}{4}$ of an inch to the foot. If the die is turned on any further, that part of the pipe passing through will have a straight thread. Under such conditions it will be much more difficult to make a tight joint.
- 87 In making the pipe connections a paste of red lead and oil is smeared on the threads after which the pipes are screwed into the connections the full depth of the threaded portion, thus making a tight joint. The gaskets used for unions should be cut to the exact size, from either sheet rubber or sheet lead. In connecting pipes that are to carry gasoline, ordinary laundry soap should be used instead of red lead, and sheet lead in place of rubber. Gasoline dissolves rubber, a fact which makes it unsuitable for this kind of work.
- 88 *Valves.*—Valves are used to control the flow of fluids in pipes. Those which allow the fluid to flow in either direction may be divided into two classes, globe valves and gate valves; those which allow the fluid to flow in one direction only are called check valves.
- 89 *Globe Valves.*—Globe valves are so called on account of the spherical shape of the body of the valve. In the small sizes used on traction engines they are usually made of

brass throughout, but for heavier work the body is of iron and the valve and valve seat of brass. Fig. 71 is a sec-



Ordinary Globe Valve. Fig. 71.

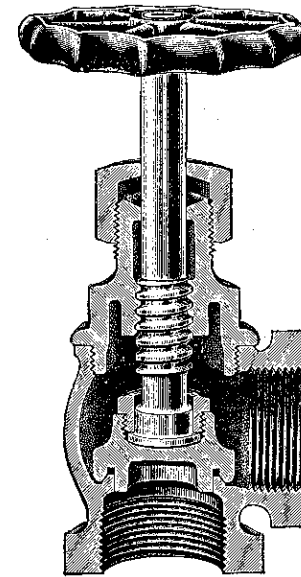
tional view of an ordinary brass globe valve; the valve disc is made of brass and when screwed down fits into a cone-shaped seat. Fig. 72 represents another globe valve having



Globe Valve with Composition Disc. Fig. 72.

a composition disc which may be removed and which may be easily renewed when worn out. These valves are made in quite a variety of styles, as regards the valve disc and valve seat.

90 Fig. 73 represents an angle valve which is used whenever it is desired to put in a stop valve where two pipes



Angle Valve. Fig. 73.

seats against the pressure of the fluid. If put in in this meet at right angles. These valves should be put in so that the pressure comes from below and the outlet is at the

side. Globe valves should be put in so that the valve way it is possible to pack the valve stem with the pressure on, but if placed the other end to, it will be necessary to cut off all pressure on the pipe before the valve stem can be packed. Furthermore, if put in in the right way there is no pressure on the packing when the valve is closed and if the hand wheel is broken it is not so difficult to open the valve *with* the pressure as against it.

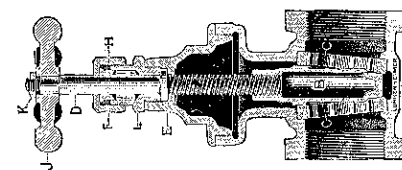
91 *The Care of Globe Valves.*—A valve that is subjected to steam pressure should never be screwed down tightly on its seat when cold, because the expansion of the metal when steam is raised will be sufficient to throw a tremendous strain on the valve seat and injure it. When the valve is hot, on the contrary, it should be screwed down tightly because the contraction of the metal on cooling will relieve the pressure of the valve on its seat to some extent. A valve never should be left partly closed so that a small stream of steam or water can blow through. The erosive action of water or steam upon brass is very marked and it only takes a short time to wear away the valve disc or seat so that it is impossible to close the valve tightly.

92 Valves having brass discs can be reground, if they become worn, and made as good as new. A simple way to do this in the field is to grind the valve in with oil and fine emery. An ordinary carpenter's brace can be used for turning the valve disc on its seat. If emery is not at hand fine grindstone dust sifted through muslin will answer the purpose. The valve stem is ordinarily packed with candle wicking. This should be twisted tightly or braided to-

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gether tightly and then given a coat of oil and graphite, after which it is coiled around the valve stem and the stuffing box gland screwed down.

93 *Gate Valves.*—Fig. 74 represents a sectional view of a gate valve. In this type of valve there are two discs which



Gate Valve. Fig. 74.

are raised and lowered by means of a screw. When screwed down tightly a wedge between the two discs presses them out against their seats. These valves offer somewhat less obstruction to the flow of fluid than gate valves but are, as a rule, not quite as suitable for very high pressures.

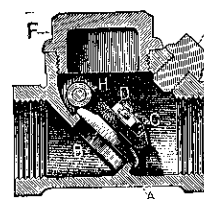


Fig. 75.
Swinging Check.

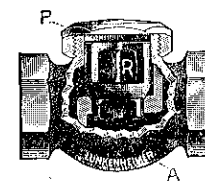


Fig. 76.
Vertical Lift
Check Valve.

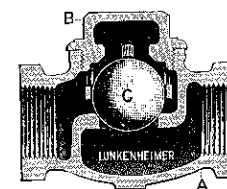


Fig. 77.
Ball Check Valve

94 *Check Valves.*—Horizontal check valves are made in three principal styles, illustrated in figures 75, 76 and 77.

Fig. 75 represents a swinging check valve; Fig. 76 a check valve having a vertical lift; and Fig. 77, a ball check valve. There is very little choice among the three. The first two may be reground if they become worn, but the last mentioned one is very difficult to repair if the ball becomes cut or grooved.

95 *Pipe Coverings.*—Steam pipes which are exposed to the air should be jacketed in order to prevent radiation and consequent condensation and loss of steam.

96 The materials used for covering pipes are hair-felt, wool-felt, magnesia and asbestos. The best insulator is probably hair-felt after which comes wool-felt, mineral wool, carbonate of magnesia, charcoal, sawdust, wood and asbestos, their insulating properties being about in the order named.

97 *The Boiler Jacket.*—The boilers of traction engines should always be jacketed, especially in the colder sections of the country, where they are exposed to outdoor conditions and where rapid currents of cold air cause great loss of heat. It would require considerable more fuel to keep up steam with an unjacketed boiler than one properly protected. The amount of saving in fuel that may be effected by jacketing depends of course upon the temperature of the outdoor air and upon the movement of the wind.

98 The principal materials used for jacketing boilers are asbestos paper, mineral wool, and wood. Since a dead air space has considerable value as an insulator, it is usual to allow from $\frac{1}{4}$ to $\frac{1}{2}$ an inch of air space between the jacket and the boiler. With this air space and asbestos

between the wood and the boiler there is little danger of the wood being burned. These insulating materials are held in place by means of a sheet iron covering which is held on by bands of brass or steel.

QUESTIONS.

1. Explain the different types of grates used in traction engines.
2. Explain the action of the exhaust nozzle and state its office in connection with the traction engine.
3. What is the correct position for the exhaust nozzle?
4. Describe two styles of spark arresters and explain their action.
5. What effect has the spark arrester upon the draft?
6. Name the safety devices every boiler should be provided with.
 7. Describe a steam gauge.
 8. Is a syphon necessary on a steam gauge?
 9. How are steam gauges tested?
10. Describe a spring safety valve and explain its action.
 11. Which is more to be relied upon, the glass water gauge or the try cocks?
 12. How should the water glass be taken care of?
13. How high should water be carried above the top row of flues?
 14. Of what advantage are water columns?
 15. What is the office of the fusible plug?
 16. What are fusible plugs filled with?
 17. How should fusible plugs be taken care of?

18. What are handholes and clean-out plugs for?
19. How are handholes packed?
20. Explain the use of both the bottom blow-off and surface blow-off.
21. How is the size of steam, gas, and water pipes designated, and how does this designation differ from that of boiler tubes?
 22. Give a list of the principal pipe fittings.
 23. What kind of "dope" is used on pipe threads to make a tight joint?
 24. Mention the classes of valves used on traction engines.
25. How may valves be reground?
26. Why should steam pipes and the boiler be jacketed?

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(By Correspondence)

LESSON WITH QUESTIONS

BOILER FEEDERS AND FEED WATER
PART IV

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

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CLARKE SCHOOL OF TRACTION ENGINEERING

(BY CORRESPONDENCE)

MADISON WISCONSIN

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PART IV.

BOILER FEEDERS AND FEED WATER.

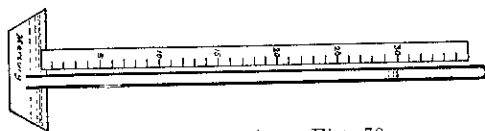
- 1 Every steam boiler should be equipped with two boiler feeders, so that if one should suddenly fail to work another would be ready. It is the duty of the engineer in charge to keep both feeders in good working order all the time. Failure to do so should be taken as a mark of incompetency and excuses should not be considered. The safety of the boiler depends largely upon the water supply and every precaution should be taken to keep it under instant control. So well is this necessity recognized that almost all boilers, no matter what purpose used for, are provided with either two pumps or two injectors, or an injector and a pump.
- 2 Since the safety of the engine is dependent so much upon pumps and injectors it is essential that the engineer in charge understand thoroughly the principles governing their action, so if anything goes wrong he will be able to locate the trouble without delay and remedy it.
- 3 In order to make the action of pumps and injectors perfectly plain it will first be necessary to review briefly some of the laws of physics governing their action.
- 4 *The Atmosphere.*—The earth is surrounded by a sea of air whose depth has been variously estimated at from 40 to 200 miles. The exact depth is not known nor need it be considered in this discussion.

BOILER FEEDERS AND FEED WATER.

- 5 Air consists principally of two gases, oxygen and nitrogen, mixed in the proportions of four parts of nitrogen to one of oxygen. Compared with solid substances with which we are familiar air has very little weight. A cubic foot at sea level weighs only about a quarter of an ounce. The pressure of the air on each square inch of surface, at the sea level, is about 14.7 pounds. Since the depth of the air above any point of the earth's surface is constantly changing, it follows that the air pressure, or weight of the air on a square inch at any particular point, is also a changing quantity.
- 6 All bodies on the earth's surface are subjected to the pressure of the air, which, according to the laws of fluids, acts with the same intensity in all directions. It acts sideways and downwards and upwards with the same amount of force and so does not incommode us because it is equal and opposite in all directions. The pressures are balanced and therefore are just as though they did not exist at all so far as bodily movement is concerned; neither does the weight of the air exert any crushing force unless it acts on one side of a body only.
- 7 A thin paper box is in no danger of being crushed because there is as much pressure on the inside as there is on the outside. However, if the pressure were removed from the inside of the box it would collapse instantly; in fact, it requires quite a strong structure to withstand 15 pounds pressure per square inch. There is hardly a building or dwelling house in the land that could stand against atmospheric pressure if all the air were removed from the inside.

3 Whenever a vacuum is established in any vessel its walls are subjected to a crushing force of about 14.7 pounds per square inch; i. e., at sea level. As we go above sea level, atmospheric pressure becomes less because the depth of the sea of air above us is less. On the tops of high mountains the atmospheric pressure is only a few pounds, so little, in fact, that there is not enough oxygen in the amount of air animals can breathe to meet bodily requirements.

9 *The Barometer.*—The barometer is the instrument used for measuring the weight of the air (see Fig. 78). It consists essentially of a glass tube about 34 inches long closed at one end and open at the other. The tube is filled with



Barometer. Fig. 78.

mercury and then inverted with the open end submerged in a cistern containing mercury. On inverting the tube, only a small amount of the mercury will flow out; the column coming to rest at a height of from 29 to 30 inches. There is no air in the tube above the mercury, and, hence, no pressure, but there is pressure on the mercury in the cistern, viz., that of the atmosphere. It is the atmospheric pressure that holds the mercury up in the tube. Since there is no air pressure on the top of the mercury and there is on the bottom of the column in the tube, the weight of the column of mercury must therefore exactly balance the

pressure of the air. It is clear, then, that the height of the mercury column measures the weight of the air at that particular place. In other words, the mercury column in the barometer exactly supports a column of air of the same diameter reaching from the earth, upwards as far as the air exists.

10 Any other liquid could be used as well as mercury, only the tube would have to be much longer. Mercury weighs 13.56 times as much as an equal volume of water. If we made a barometer of water it would necessarily be 13.56 times as long as the mercury column, i. e., 13.56 times 30 equals 406.8 inches, or 33.9 feet. In other words, the height of a column of water which can be supported by atmospheric pressure is roughly 34 feet; i. e., assuming that the total amount of atmospheric pressure can be utilized in forcing water up in the tube.

11 The height to which water may be forced in a tube by atmospheric pressure can be found in another way. For example: A column of water 1 inch square and 12 inches high, weighs about .434 of a pound. The total height of water then necessary to balance 14.7 pounds, or atmospheric pressure, can be found by dividing 14.7 by .434; the quotient will be 33.9, as before.

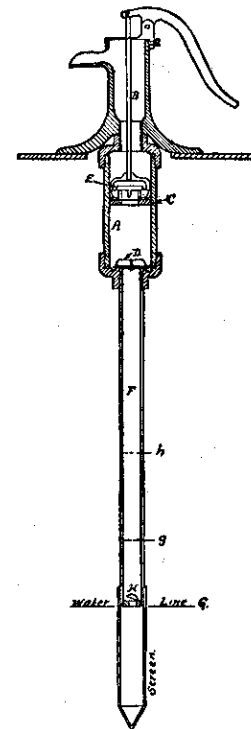
12 If a long vertical pipe had the lower end submerged in water and air were removed from the inside of the pipe above the water, atmospheric pressure would force water up in the tube. If all the air could be removed from the inside of the pipe, the height to which water would rise would be as before, 33.9 feet. If a part of the air inside

of the tube is removed, making only a partial vacuum, water will rise to a height proportional to the amount of air pressure removed. Or, looked at in another way, the water will rise and compress the remaining air within the tube until the air pressure, together with the weight of the water on the inside, exactly balances the air pressure on the outside.

- 13 All suction pumps depend upon atmospheric pressure to force the water up into the pump chamber. The pump exerts no drawing force, it removes the air from the suction pipe and air pressure causes the water to rise. Injectors depend upon the same principle for raising water from a lower level to the injector. Owing to the friction of the valves in the pump and to slight leakages, it is impossible to raise water to the theoretical height above mentioned. A pump in good order will raise water 25 feet, but it is not usual to figure the lift of a suction pump at more than about 20 feet. An injector cannot be depended upon to lift water more than about 15 feet. The height to which a pump or injector will force water, however, is an entirely different matter, and depends upon either the strength of the pump or the steam pressure used in the injector.

- 14 *The Suction Pump.*—Now that atmospheric pressure is understood it will be easier to explain the action of a pump. Fig. 79 is a cut of a common suction pump, A is the barrel of the pump, B is the plunger rod, C is an air tight piston, D and E are valves, both of which open upward. F is the pipe leading downward to the water and G is the surface of the water. The action of the pump is as follows:

- 15 When the piston is forced downward, valve E opens and the air displaced by the piston rushes through to the



Common Suction Pump. Fig. 79.

upper side. At the same time valve D closes so that air cannot be forced out at the bottom of pipe F. When the

piston again moves upward it sweeps the air with it, leaving a partial vacuum underneath. Since the pressure in the pump chamber is now less than that on the surface of the water, the water will rise to such a point that the remaining air in the pump chamber will be compressed to such a point that this pressure added to the weight of the column of water will equal atmospheric pressure. The same cycle of changes occurs every stroke until finally the water rises and covers the pump plunger and is then forced out at the spout. H is a foot valve, placed near the surface of the water to prevent water from flowing back out of the suction pipe.

- 16 A suction pump will not lift hot water because when the air pressure is reduced above the water in the pump chamber, the water will burst into steam and destroy the vacuum. Under ordinary atmospheric pressure of 14.7 pounds per square inch, water boils and forms steam at 212 degrees F., but if the pressure is reduced below atmospheric pressure, water will boil and form steam at lower temperatures, as shown in the table below:

17

TABLE III.

Absolute pressure in lbs. per sq. in.	Temperature Fah. at which water boils.
1	102.0
2	126.4
3	141.6
4	153.1
5	162.3
6	170.1
7	176.9
8	183.0
9	188.4
10	193.3
11	197.8
12	202.0
13	205.9
14.7	212.0

- 18 If the supply of water is above the pump, so that it can flow into the pump chamber, the pump will force water of any temperature into the boiler.
- 19 *Priming a Pump.*—The necessity for priming a pump arises when the plunger valve leaks, thereby making it impossible to obtain a vacuum in the suction pipe. The effect of priming is to make a water piston. When the leak is not so great as to allow the water to get away rapidly a piston of water will rest on the top of the plunger, thus making a practically air tight water plunger which pre-

vents air from leaking into the suction pipe. By this means air can be exhausted from the suction pipe and the pump be made to work.

- 20 *Absolute Pressure.*—Absolute pressure is measured from the zero of pressure, i. e., from a vacuum. An ordinary steam gauge begins with atmospheric pressure, i. e., it does not register any pressures below that of the atmosphere. Zero pounds pressure on the gauge is the same as 14.7 pounds atmospheric pressure. If we want to reduce gauge readings to absolute pressures we must add 14.7 pounds to the reading of the gauge. If the gauge reading is 50 pounds, the absolute pressure is 50 plus 14.7 or 64.7 pounds; hence, the rule.

- 21 *Rule I.*—To reduce gauge pressures to absolute pressure, add 14.7 to the gauge reading.

- 22 *Force Pump.*—If the common suction pump just described were fitted with a delivery pipe instead of with a spout, and if a check valve were placed in the bottom of this delivery pipe, water could be forced as high as the strength of the working parts of the pump would permit.

- 23 *Traction Engine Boiler Feeders.*—Traction engine boiler feeders may be divided into two classes, pumps and injectors. Both are used to about an equal extent and there is perhaps no choice between them. As a rule, the injectors cost a little less than pumps and are a little easier to take care of. They are, however, rather more difficult to repair than pumps when they get out of order.

- 24 *Traction Engine Pumps.*—Traction engine pumps may be divided into two classes, dependent pumps and inde-

pendent pumps. The former can operate only when the engine is running, the latter whenever there is enough steam pressure in the boiler. In the former the plunger of the pump is fastened to some moving part of the engine and operates just as any single acting force pump.

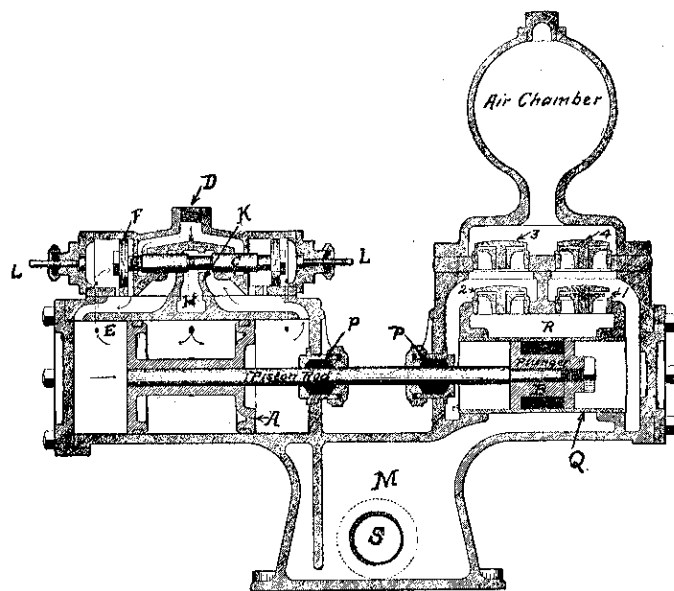
- 25 The independent pump is a combination of engine and pump. It is, in fact, a complete engine whose piston rod is connected with the plunger of the pump, compelling the latter to move in accordance with the movements of the steam piston.

- 26 As to the comparative merits of the two pumps there is perhaps little choice. The dependent pump is usually simpler in construction than the independent, easier to keep in working order, and its first cost is considerably less. The independent pump, on the other hand, has the advantage of being able to run whenever there is steam in the boiler without making it necessary to start the engine. The matter of choice appears to resolve itself largely into a matter of taste rather than efficiency, since the merits and defects of the two pumps seem to be about equally balanced.

- 27 Cross-head pumps and eccentric pumps belong to the first mentioned class, while the Marsh, Moore, Clark and Duplex belong to the second class. A description of each pump will appear under its own heading.

- 28 *The Marsh Steam Pump.*—The following explanation must be read with reference to the cut, Fig. 80. The right end of the pump is the water end. The left is the steam end. The spool A is the steam piston, B is the water piston, and C is the steam valve.

- 29 Steam from the boiler is admitted through the pipe D and flows in the direction of the arrows. There is a passage way leading from D to the center of the cylinder, so that the space between the flanges of the spool is always



Marsh Steam Pump. Fig. 80.

filled with live steam. This provides motive power to throw the valve when the piston reaches the end of its stroke. When the flange of piston A, in traveling to the left, passes port E, live steam from the middle of the piston A rushes in behind the valve head F and pushes it toward

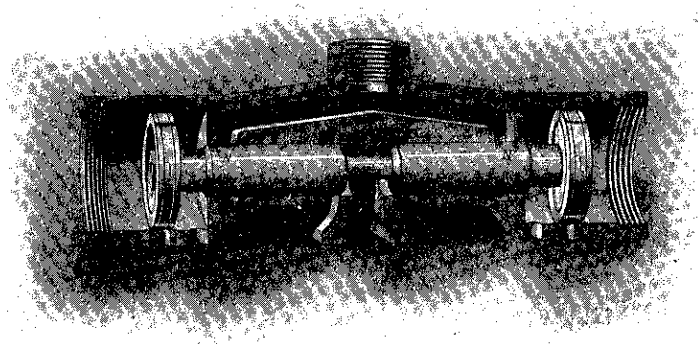
the right. This movement allows steam to flow from D around the neck of the valve at G and down into the cylinder. The piston now starts toward the right, port E is uncovered, and the steam behind the retreating piston flows in behind F. The valve head F is now acted upon by two forces, live steam on the right hand side, and steam of lower pressure, which pushes the piston, on the left. The live steam tends to close the valve, while the cylinder steam keeps it open. Since the area exposed to the steam is greater on the left side than on the right, by the amount of the cross section of the valve stem G, the total amount of pressure acting toward the right will in general be greater and tend to keep the valve open throughout the stroke. The exhaust steam escapes from the right side of the cylinder in the direction of the arrows, flows past the bridge K, and around the reduced middle part of the valve body and so down through H into the exhaust pipe, where it may be turned out into the air or into the lower part of the pump M, where it mingles with and heats the feed water.

- 30 *Explanation of the Governing Principle.*—If the piston moves faster than steam can be supplied through the small annular space at G, the pressure on the left side of the piston will fall below boiler pressure, and hence the pressure on the left side of F will also fall, thus allowing the incoming boiler steam on the right of F to exert the greater pressure and push the valve to the left. The body of the valve will now fill the opening at G and steam will be cut off while at the same time the exhaust steam acts as a

cushion on the right side of the piston and tends to stop it.

- 31 The exact position of the valve at any moment, and consequently the amount of steam admitted to the cylinder, depends upon the relative strength of the two forces tending to move the valve in opposite directions. When the piston moves very rapidly the steam expands behind it and the cylinder pressure, which tends to open the valve, falls; while admission steam, which tends to close the valve, remains the same and hence forces the valve partly shut, thus throttling the steam supply and slowing down the piston.

- 32 The small holes at N (see Fig. 81), which communicate with the ends of the valve, drain the steam pipe when the



Valve of Marsh Pump. FIG. 81.

pump is stopped and aid in governing by slowly equalizing the pressure driving the piston with that in the steam pipe.

In case the valve gets stuck it may be started by hand by means of the tappets L.

- 33 The flanges of the steam piston A are provided with spring packing rings making a steam tight joint between the piston and the cylinder. The distance between the flanges is such that live steam from D can flow in between the two heads when it is at the end of its throw in either direction. The exhaust steam flows from the cavity H through a cored opening not shown in Fig. 80.
- 34 *The Water End of the Pump.*—This end of the pump is like any ordinary double acting force pump. The pump plunger works back and forth in the brass cylinder Q. The cavity R extends entirely around the cylinder and communicates with the water space M and the suction pipe S.

- 35 In order to make the action of the pump clear we will assume that the plunger starts from the extreme right end of the cylinder, then, when it moves toward the left it forces the air in front of it, out through the check valve 3, while at the same time air from the cavity M, actuated by atmospheric pressure on the top of the water in the supply tank, lifts valve 1 and fills the right end of the cylinder. This operation is repeated alternately until all the air is exhausted from the suction pipe and water fills the pump chamber. The reciprocating motion of the pump plunger forces water alternately from each end of the cylinder, through check valves 3 and 4, into the delivery pipe. When water flows out through valve 3, it flows into the right end of the cylinder through check valve 1, and when it is being

delivered through valve 4 the left end of the cylinder is filling through valve 2. It will thus be seen that the pump is double acting, i. e., it delivers water to the boiler on both strokes.

36 The delivery water first enters the air chamber before passing on to the delivery pipe. The upper part of this chamber always contains some air which is compressed by the water and acts as a cushion, thus relieving the delivery pipe and the upper part of the pump from sudden shock. Besides, the compressed air causes a much steadier flow of water from the delivery pipe. All single plunger force pumps are provided with an air chamber.

37 *The Pump Plunger.*—The pump plunger, as will be seen from the cut, consists of a flanged piston having one removable head. The annular space between the flanges is filled with a ring of packing. This ring is composed usually of canvas and rubber and is made especially for the purpose. Before starting out in the fall several extra packing rings should be placed in the tool box to be used in case repairs are necessary. The piston rod is packed where it enters the steam cylinder and the water cylinder, shown at P in the drawing. Braided candle wicking saturated with oil and graphite is usually used for this purpose.

38 *Lubrication of Pump.*—The water end of pumps do not need lubrication but the steam end must be oiled continuously, just as any steam engine is lubricated. The lubricator should hold at least a half a pint, and should be connected with the steam pipe immediately above the pump. A good grade of cylinder oil should be provided. Owing

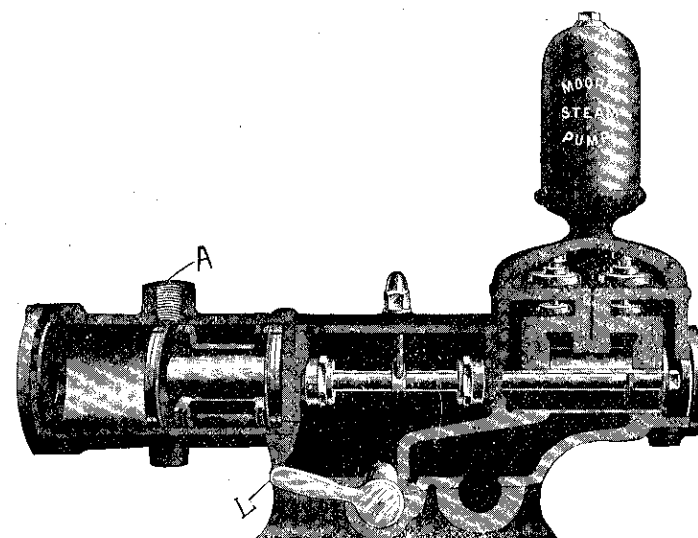
to the rather delicate construction of the valve and the small difference in pressure which trips it, difficulty is often experienced through its sticking if not properly lubricated. While some pumps will run, even if they are not lubricated continuously, the same cannot be said of the Marsh pump. In order to be sure of its operation a small quantity of oil must be supplied continuously.

39 *Starting the Pump.*—In starting the pump the first thing to do is to throw the exhaust lever over so that the exhaust is turned into the atmosphere, then open the bib cock on the water cylinder hood and open the valve in the suction pipe. Now turn on steam and start the lubricator. If the exhaust is turned into the body of the pump first the vacuum will be destroyed and water cannot rise in the pump cylinder. After the pump begins to deliver, the exhaust lever may be turned in the other direction, thus turning the exhaust steam into the suction chamber in the body of the pump. In this way all of the steam required to run the pump is returned to the boiler and at the same time the feed water is heated to a considerable extent, thereby effecting some saving in fuel and relieving the boiler from the strains due to sudden cooling which would be caused by introducing cold feed water. If the bib cock is not open the first two or three strokes of the pump are not apt to compress the air in the delivery pipe to such an extent that on the next stroke of the plunger the air will simply be compressed in the cylinder, thereby closing the lower check valves and making it impossible for water to enter the pump. A pump in this condition is said to be air bound.

40 *Pump Connections.*—Care must be taken in piping up a pump to use pipe as large as the pump connections call for. The pipe should be tested to make sure that there are no cracks or flaws and reamed at the ends in order that the area of the pipe shall not be reduced through the burr formed in cutting. Care should be taken to clean all chips and dirt from the inside of the pipes, otherwise obstructions may find their way either into the steam cylinder or into the check valves of the water cylinder; not only stopping the pump but causing damage to the moving parts. A check valve should be placed on the delivery pipe close to where it enters the boiler, with a stop valve between it and the boiler.

41 *The Moore Steam Pump.*—The explanation given for the water end of the Marsh pump applies equally well to the Moore pump; the steam end, however, is very much different. A longitudinal section of this pump is shown in Fig. 82. Fig. 83 represents the piston and plunger and Fig. 84 the valve. Fig. 85 shows piston, plunger and valve assembled. The steam piston consists of a cylinder having flanges at each end provided with spring packing rings. The distance between the flanges is a little greater than one-half of the length of the cylinder, thereby compelling live steam from the supply pipe A, to first enter the cylinder between the piston flanges. The inner part of the valve is provided with a wide central groove H and two narrower grooves on each side. These narrower grooves communicate with the steam space between the piston flanges through a number of holes drilled through the

valve. The position of the valve in the pump is shown in Fig. 82. The cylindrical part of the piston is provided with two pair of transverse slots on opposite sides near



Moore Steam Pump. Fig. 82.

each flange, one wide, the other narrow. One pair is shown at E and D in Fig. 83. A longitudinal steam port in the interior of the piston connects E and D with the right end of the piston and a similar port connects the other two slots with the left end of the piston.

42 *The Action of the Pump.*—The action of the pump is as follows: Referring to Fig. 82, the piston is represented

at the end of its stroke with the valve in its proper position after having been shifted. Steam can now pass between the piston head and valve and enter one of the narrow slots E, from which it passes through the longitudinal port

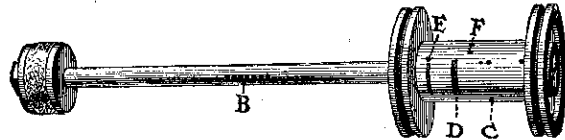


Fig. 83.

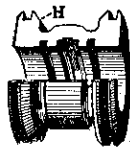


Fig. 84.

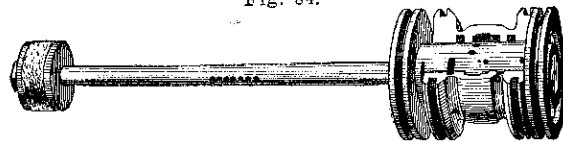


Fig. 85.

Valve and Plunger of Moore Steam Pump.

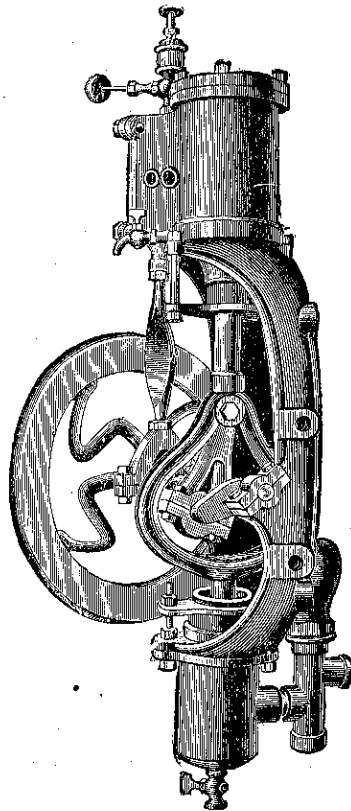
in the body of the piston to the right end of the piston, where it moves the whole plunger to the left. When the spring ring in the valve passes the steam port A, steam enters between the flanges of the valve (Fig. 84) and passes through the holes into one of the smaller grooves in the valve, from which it passes into the wide slot D (Fig. 83) and thence through one of the longitudinal ports to the end of the piston. Since boiler steam occupies the space be-

tween the heads of the piston, the valve is held in place to the end of the stroke. When the piston reaches the end of its stroke a groove in the end of the cylinder allows the steam between the valve and piston head to escape. Then, when the right hand flange of the valve passes steam port A, live steam between the valve flange and piston flange throws the valve over into the proper position for the backward stroke.

- 43 *The Exhaust.*—When the valve is shifted to its extreme position the wide central groove in H covers both the slots E and D or their corresponding pair. The steam can then pass back through the longitudinal ports and enter the wide groove in H. From this point it passes through the round ports F into the hollow valve rod and thence out through openings B, into the central portion of the pump, from which it can be turned, by means of a two-way valve L, either into the atmosphere or into the suction chamber where it unites with the feed water.

- 44 *The Clark Pump.*—The steam end of this pump is just like any other plain slide valve engine. The cylinder and steam chest are cast in one piece and steam is supplied to the cylinder through a plain D slide valve which is so arranged that the engine takes steam full stroke and exhausts full stroke. The lower part of the piston rod is also the pump plunger. The water end of the pump consists of a brass cylinder, in which the plunger works, and two check valves. Its action is similar to that of the cross-head pump, which will be described in detail on the next page.

- 45 A heavy fly wheel on the crank shaft maintains a steady motion and the handle with which it is provided makes it possible to use this pump by hand, either to pump up the



Clark Pump. Fig. 86.

BOILER FEEDERS AND FEED WATER.

boiler, or as a force pump in cleaning the boiler. Fig. 86 illustrates the leading features of this pump.

- 46 The drain cock at the bottom of the steam cylinder should be opened when steam is turned on to take care of the water of condensation. Both it and the drain at the bottom of the water cylinder should be opened when the engine is shut down for the night.
- 47 *Duplex Pumps.*—A Duplex pump consists of two complete pumps placed side by side. The piston rod of one pump is connected by means of a lever to the valve of the opposite steam cylinder, thus each pump piston drives the valve for its neighbor. The effect of this arrangement is that when one piston arrives near the end of its stroke the other piston is just beginning, so that the stream of water in the delivery pipe is kept constantly moving, first by one piston, then by the other. The strains in the piping induced by a column of water whose motion is irregular is thus avoided, and no air chamber is necessary. Fig. 87 is a sectional illustration of a Gardner duplex pump.
- 48 Each water cylinder is provided with four valves and so closely resembles the pumps already described as to need no detailed description.
- 49 The steam valve, however, is entirely different. It consists of a plain D slide valve having neither inside nor outside lap, consequently steam is admitted to the cylinder during the entire stroke.
- 50 In this style of pump there are two steam ports and two exhaust ports. Steam flows into the cylinder around the ends of the valve through the two outside ports, and the

Gardner Duplex Pump. Fig. 87.

on each stroke in cubic inches, by the number of strokes per minute and divide the product by 231; the result is the number of gallons per minute, provided no water leaks by the piston. It is usual, however, in all such computations, to allow a small amount for leaking, say from 2 per cent to 5 per cent.

56 *Example.*—How much water will a pump deliver per minute if the plunger is 3 inches in diameter and has a travel of 5 inches, if it makes 100 strokes per minute?

57 *Solution.*— $3 \times 3 \times .7854$ equals 7.0786; equals the area of the plunger.

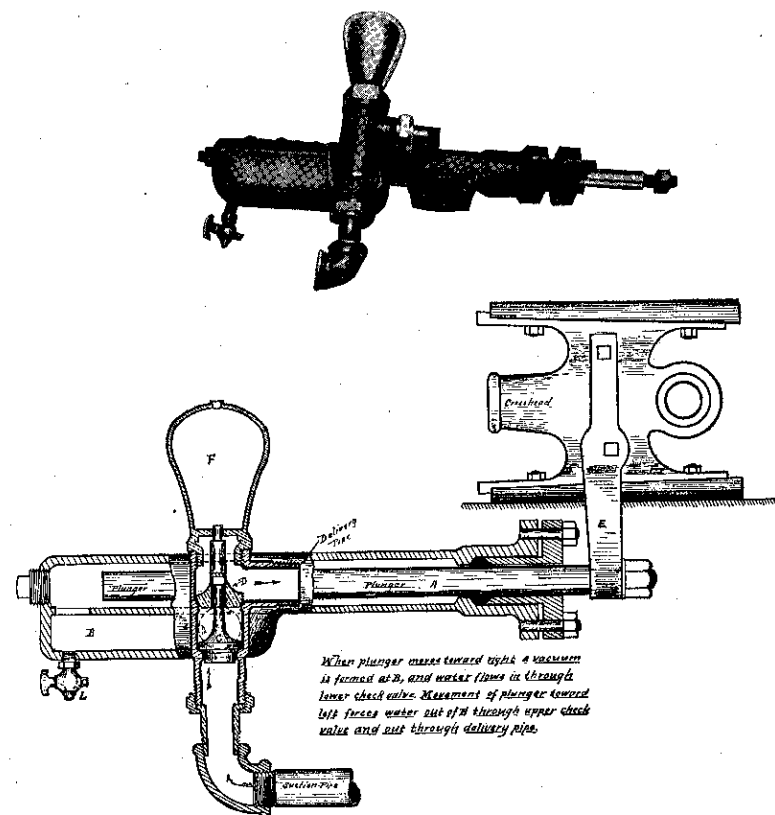
58 7.0786×5 equals 35.393, the volume swept thru by the piston.

59 35.393×100 equals 3539.3 the total number of cubic inches of water moved per minute.

60 3539.3 divided by 231 equals 15.3 gallons.

61 *Care of Duplex Pumps.*—The steam end of these pumps should be oiled continuously, while running, with a good grade of cylinder oil. On shutting down at night both the steam cylinders and water cylinders should be drained. Care should be taken not to screw up the stuffing box glands too tightly, as the friction of tight packing at this point may cause the pumps to stop working. These points in all pumps should be frequently repacked with a good soft packing.

62 *The Air Chamber.*—The air chamber is placed on the delivery pipe and is generally made a part of the pump. The object of the air chamber is to relieve the pump and its connections from sudden strains due to the discharge



Cross Head Pump. Fig. 88.

of water from the pump and to insure a steady stream of water flowing through the delivery pipe.

- 63 The action of the air chamber is as follows: When the water is first forced into the delivery pipe it rises rapidly into the air chamber and compresses the air in the upper part. This being elastic, re-acts upon the water when the plunger starts in the opposite direction and forces it into the boiler. Water contains enough air to supply all that is needed to keep the air chamber filled.
- 64 *The Cross-Head Pump.*—The cross-head pump, as its name implies, is driven by the cross-head of the engine. An arm from the cross-head is attached to the pump plunger and moves it back and forth whenever the engine makes a stroke. Both a sectional view and a half-tone of this style of pump appears in Fig. 88. A represents the pump plunger, which is a plain bar of iron. B is the body of the pump, C is the lower check valve in the suction pipe, and D the check valve in the delivery pipe. E represents the arm attached to the cross-head which drives the pump plunger. The air chamber is shown at F and a globe valve, not shown in the figure, is placed in the suction pipe. A check valve, and a stop valve, between the check valve and the boiler, are placed on the delivery pipe.
- 65 The pump plunger is packed where it enters the body of the pump. Braided candle wicking or ring packing may be used at this point.
- 66 *Operation of the Pump.*—When the pump plunger is drawn out a partial vacuum is formed in the cylinder, which allows the air in the suction pipe to expand. Air pressure on top of the water in the tank forces water up

- the suction pipe until the pressure of the air inside the pump together with the weight of the column of water in the suction pipe is the same as that on the outside. On the inward stroke of the plunger a volume of air, equal to the volume of the plunger, is driven out of the cylinder through check valve D and out through a pet cock in the delivery pipe, not shown in figure, which should be open on starting. On the next outward stroke of the plunger, valve D drops to its seat and water rises in the suction pipe. After several strokes of the plunger, water appears in the cylinder and is forced out into the delivery pipe. The pet cock should be closed when water appears at that point. Water will then rise in the air chamber and compress the air therein and on the next stroke of the plunger this will expand and keep a steady stream flowing into the boiler.
- 67 A safety cap is placed on the top of the air chamber which will blow out if the pressure becomes too great, as sometimes happens if the stop valve on the delivery pipe is accidentally closed.
- 68 *Regulation of the Pump.*—While the engine is running, the pump plunger is also moving. In order to prevent it from delivering water, the valve on the suction pipe may be closed or the pet cock L left open. If the suction valve is closed, the packing is under the strain of atmospheric pressure, while if L is opened, air is drawn into the cylinder on the outward stroke of the plunger and expelled through the same orifice. In this case the valve in the suction pipe may be left open. Then in order to start the

pump working all that is necessary to do is to close the valve L. The amount of water delivered to the boiler may be regulated by the suction valve. If it is opened only a small amount, enough water to fill the cylinder will not be enabled to get through and so only a small quantity will be delivered at each stroke of the plunger.

- 69 The cross-head pump is a very simple pump, perhaps the simplest used on traction engines. The objections against its use are that it runs only when the engine runs and is apt to be a little noisy.
- 70 *The Eccentric Pump.*—An eccentric pump is used on some engines but it needs no separate description. It is exactly similar to the cross-head pump, with the exception that the plunger is operated by means of an eccentric on the main shaft instead of from the cross-head.
- 71 *Pump Troubles.*—Whenever a pump fails to work the engineer should determine first whether the trouble is in the suction pipe, in the mechanism of the pump itself, or in the delivery pipe. It is sometimes difficult to locate the exact cause of the trouble. In such a case the best way to proceed is to detach both the suction pipe and the delivery pipe, then run the pump and hold the hand over the suction pipe connection and note if a vacuum is formed. If the pump seems to have suction the trouble, then, is not in the pump itself, but is somewhere in the suction pipe. If the pump does not have suction the difficulty is in the pump; either in the plunger or in the check valves.
- 72 If a pump will run but does not get water it may be due to absence of water in the tank, a leak in the suction

pipe, a leak of air into the pump cylinder itself or an obstruction in the suction pipe.

- 73 If the suction pipe leaks, air will enter and destroy the vacuum formed by the pump, thus preventing atmospheric pressure from forcing water up to the pump cylinder.
- 74 If the pump plunger leaks, air will simply flow from one side of the plunger to the other and a vacuum will not be formed in the suction pipe; or, if the check valve in the suction pipe leaks, the pump plunger will draw the air out of the suction pipe and then force it back again, thus preventing water from rising to the pump cylinder.
- 75 If the check valve in the delivery pipe leaks, either water or air will flow back into the pump cylinder, thus preventing a vacuum from being formed therein. These valves can be reground by using flour of emery, as described in Part III.
- 76 In using a hose for a suction pipe that is somewhat worn, atmospheric pressure may pinch it together and prevent air from flowing freely to the pump.
- 77 A strainer should always be placed on the bottom of the suction pipe to prevent chaff or dirt from being drawn up into the pump. Failure to provide the suction pipe with a strainer is almost certain to result in trouble in the check valves of the pump. Dirt or grit in the water is hard on the pump, because it has a tendency to cut out the cylinder and cause a leaky piston.
- 78 If a pump will run and water is delivered from the pet cock, at the base of the air chamber, but will not enter the boiler, the trouble will surely be found in the delivery pipe.

- 79 The check valve near the boiler is a frequent source of trouble. Dirt or sediment is apt to collect in the hinge and cause it to stick shut. Sometimes it can be started by tapping lightly with a hammer; care should be taken, however, not to strike the valve very hard and thus deform it.
- 80 Occasionally the difficulty may be found in that part of the delivery pipe which is inside the boiler. The cause of trouble at this point is generally due to the pipe becoming filled with scale or sediment. Delivery pipes which are provided with a spray nozzle on the end are very apt to become stopped by scale forming in the small orifices of the nozzle. In this case if water enters the boiler at all, it can only do so by bursting the pipe.
- 81 If the pump cylinder is cut the only remedy is to get a new one or else, if there is stock enough, have the pump rebored.
- 82 Ring packing should always be used in packing the water plunger of independent pumps. In case of emergency hemp packing or candle wicking may be made to serve the purpose for a short time.
- 83 *The Care of Pumps.*—At the close of the season when the engine is laid up, the packing should be removed from the stuffing boxes, and the cylinder and valves of the pump should be thoroughly oiled. Unless the engine is put in a dry building it is better to disconnect the pump, clean it, oil it, and put it in a dry place. If left out of doors all the winter it will become rusted and can only be started after dosing liberally with kerosene.

INJECTORS.

- 84 *Classification.*—Injectors are divided into two classes, lifting and non-lifting. Lifting injectors, as the name implies, raise the water from a lower level while non-lifting injectors will not.
- 85 A non-lifting injector must either be placed below the water tank, so that water will flow into it by gravity, or else be attached to a pressure main in order to insure a supply of water. Its action does not differ from the lifting injector aside from the one feature of not being able to draw the water from a lower level. No detailed explanation of it need be given.
- 86 Lifting injectors are again divided into two classes, automatic and positive. Automatic injectors have a single set of tubes and positive injectors have a double set.
- 87 Automatic injectors are used on traction engines and in places where the level of the water in the supply tank fluctuates a great deal. Their adaptability for this sort of work lies in the fact that if the end of the suction hose is out of water for an instant, causing the suction to break, it will immediately pick up and begin working again when the water covers the suction pipe. Positive injectors will not do this. If the suction breaks, the steam supply must be shut off and the injector started again.
- 88 Where there is no danger of the suction pipe becoming

uncovered the positive injector is a very desirable instrument. It will handle hotter water than the automatic and generally may be made to deliver against a higher pressure, but the fact that it will not pick up again when the suction breaks, makes it undesirable for traction engine purposes. In the automatic injector the over-flow valve is closed automatically; in the positive injector it must be closed by hand.

89 *Principles of Action.*—The injector is one of the most interesting pieces of apparatus the steam engineer has to deal with and it is also one of the hardest things to explain in a perfectly clear way without the use of mathematics.

90 It seems incredible that a stream of steam can be taken from a boiler and passed through a machine, having no moving parts, be made to pick up a quantity of water many times greater than its own weight and go back into the boiler against the pressure from which it started. This, however, is what the injector actually does. To make its operation plain, we will first consider the relative velocity of water and of steam flowing from the same boiler.

91 If a pipe leading from the water space of a boiler under pressure is provided with a valve, and this valve is opened, the water will flow out with a velocity which is directly dependent upon the pressure therein. The velocity of the water will be exactly equal to the velocity a stream would have flowing from a reservoir whose height is sufficient to give the same pressure as that of the steam. For example, suppose the boiler is under 120 pounds steam pres-

sure. (See Fig. 89.) Now, since a column of water one foot high exerts a pressure of .434 of a pound per square inch, as shown on a previous page, it follows that a column of water which will give a pressure of 120 pounds must be as many feet high as the quotient of 120 divided by

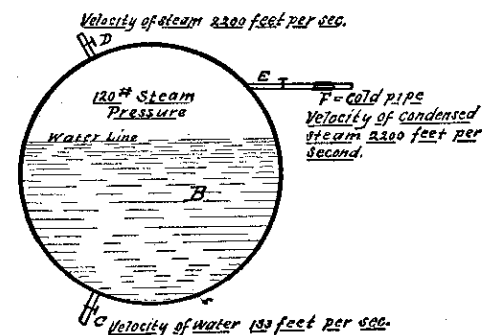
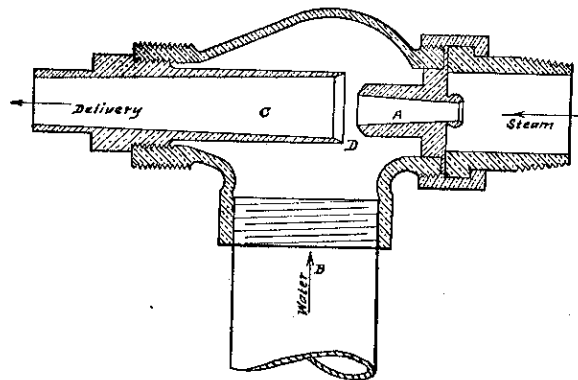


Fig. 89.

.434, or 276 feet. The velocity of water falling a distance of 276 feet is almost 133 feet per second; a fact which can be verified by the laws relating to falling bodies. This also measures the velocity with which water will flow from the boiler under discussion.

92 The velocity of steam flowing from the steam space of the same boiler will be, in general, 15 to 18 times as great as the velocity of water or somewhere in the neighborhood of 2,200 or 2,300 feet per second. If this steam, as it rushes from the boiler, could be passed through a perfectly cold pipe so as to be instantly condensed, the result-

ing water would have exactly the same velocity as the steam and could easily force its way back into the boiler against a stream of its own size. In order for a stream of water to re-enter it must have a velocity somewhat greater than the stream would have flowing out under boiler pressure. In this case it must have a velocity greater than 133 feet per second. Since the condensed



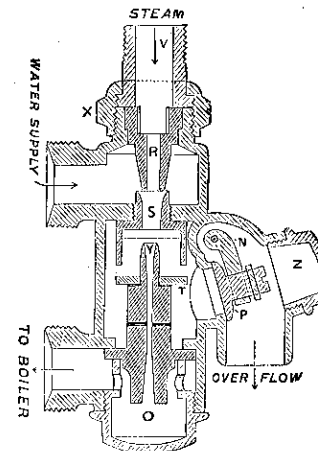
Ejector. Fig. 90.

steam has a velocity upwards of 2,000 feet per second, it is evident that it could carry with it a considerable extra amount of water and still have velocity sufficient to enable it to overcome boiler pressure.

- 93 *The Ejector.*—Fig. 90 is a sectional view of one of the simplest instruments embodying the injector principle. Steam enters at A, water at B, and C is the delivery pipe. When steam is first turned on, it rushes through the steam

jet and out through the forcing tube. This carries with it whatever air may be in the combining chamber, thus forming a vacuum in the upper part of the suction pipe, which causes water to rise and fill the body of the ejector. The steam now meets the stream of water from the suction pipe and gives to it a high velocity, but at the same time it is condensed itself. The stream which emerges from pipe C is composed of the water which rises in the suction pipe and the condensed steam which flows in at A.

- 94 Ejectors are used to lift water by suction a few feet or to deliver water to a considerable height. They are not



Penberthy Automatic Injector. Fig. 91.

suitable for boiler feeders because the delivery jet has not very great velocity. Their principal use about a traction

engine is for filling the water tank. They are sometimes called syphons, and sometimes jet pumps, but in all cases the principle of action is just the same. They will raise water from a depth of 10 or 12 feet and force water to a height in feet about equal to the steam pressure in pounds.

95 *Description of the Injector.*—The automatic injector differs from the ejector in the position and number of its jets or tubes and also in having an over-flow valve, as will be seen by referring to the sectional drawings of a Penberthy Automatic Injector. (Fig. 91.)

96 Steam flows from the boiler through the steam connection V and rushes through the steam jet R and suction jet S, carrying along with it whatever air there may be in the suction pipes, thus forming a vacuum in the combining chamber between jets R and S. This steam being light and having comparatively little momentum, passes into the space surrounding the delivery jet Y, from which place it escapes into the air with the air from the suction pipe by lifting the check valve P.

97 Atmospheric pressure, acting at the same time on the water in the tank, causes water to rise to the combining chamber, where the jet of steam strikes it and is condensed, but in doing so it imparts a high velocity to the water, enabling it to pass through the delivery jet and so on to the boiler. When steam first passes through the injector a stronger vacuum is formed in the combining chamber than in the lower part, thus causing the little disc T to rise on the jet Y until it is seated against the jet S, thus making a practically continuous jet of S and Y when the injector is working.

98 It is this disc T, that makes the injector automatic in action and enables it to pick up and start working again when the suction breaks.

99 When the air is exhausted from the injector the check valve P, is closed by atmospheric pressure from the outside and held forcibly to its seat as long as the injector is delivering water to the boiler. As soon as the injector loses suction the steam pressure on the inside opens this valve and allows steam to escape freely into the air.

100 The combining space between jets R and S takes the place of the perfectly cold pipe mentioned under the heading "Principles of Action" and illustrated in Fig. (89).

101 Just as soon as the steam is condensed in the combining chamber it gives up its velocity to the incoming water and having so much more weight than the steam, added to its velocity, has no trouble in overcoming boiler pressure and entering the boiler.

102 The size and particularly the shape of the different jets are designed to give both the steam and water the maximum velocity.

103 It can easily be seen from the foregoing explanation that the stream flowing through jets S and Y must be purely liquid, that is, contain no steam or air, otherwise the stream would not have momentum enough to enter the boiler and consequently would expand in the body of the injector and force the overflow valve open. The same thing will happen also if the supply water is too hot to condense all of the steam, consequently it must be plain that an injector can

not handle hot water even if it flows in by gravity. In this respect its action differs from that of a pump.

104 If, on the other hand, too much water is supplied for the amount of steam, it will not have enough velocity to enter the boiler and so water will be forced out at the overflow. When steam appears at the overflow it is generally evidence that there is not enough water supplied to condense the steam or else that the supply water is too hot. When water appears at the overflow it is evidence that the steam pressure is too low or that enough is not supplied to give the water sufficient velocity to pass into the boiler.

105 *The Action of the Ring on the Delivery Jet.*—In all automatic injectors it is necessary to provide a ring or bushing whose purpose it is, at the proper moment, to close the space between the suction jet and the delivery jet, thus making of them practically one continuous tube when the injector is delivering water to the boiler and two separate jets on starting.

106 When steam first rushes through the injector it must have a free open exit to the atmosphere in order to have sufficient velocity to carry the air from the combining chamber and feed pipe. Consequently this ring or bushing shown in Fig. 91 is dropped down and allows the steam to escape from the space between the suction jet and the delivery jet.

107 If the bushing were held in place against the suction jet the steam could not pass out freely enough through the small openings in the delivery jet, and consequently it

would back up into the suction pipe, and thus prevent a vacuum from being formed at that point.

108 When water rises to the combining chamber the steam is condensed and a better vacuum is formed at that point than in the chamber below, consequently this bushing is forced up against the suction jet and held in place by a difference in pressure which always exists between these two chambers. When the suction breaks the vacuum is destroyed in the combining chamber, the ring drops back, and a free exit is made for the steam through the overflow.

109 The small holes in the delivery jet are for the purpose of draining the water and vapor from the space surrounding it, and maintaining a vacuum which is necessary at this point to seat the overflow valve.

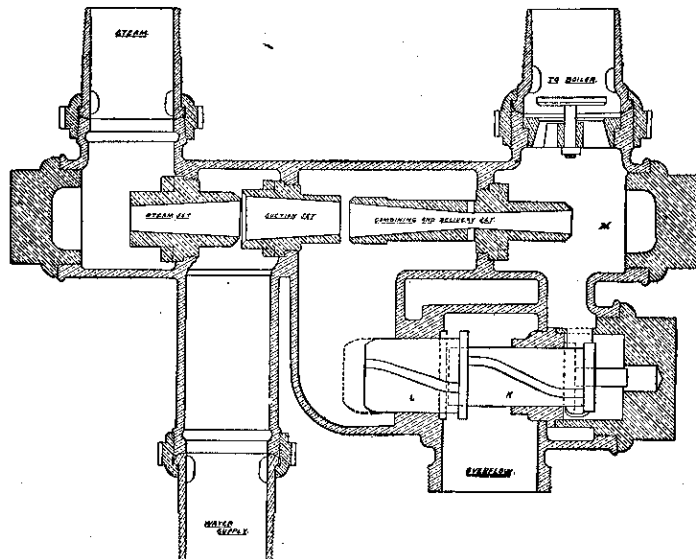
110 *The Penberthy Auto Positive Injector* is made the subject of illustration in Fig. 92. It differs from the ordinary automatic injector in having two exits for the overflow, and from the positive type of injector in having only one valve to operate in starting; namely, the valve in the steam pipe.

111 The operation of this injector may be explained as follows. When steam first flows through the jets it escapes from the vacuum chamber by way of valve L to the overflow. When water rushes through both chambers it first opens valve K wide and expels the air from the vacuum chamber.

112 The pressure of water on L now forces it toward the left until it strikes valve K, and aided by atmospheric pressure, forces K to its seat. Both valves are now held

forcibly shut by the pressure of water in the delivery chamber, M.

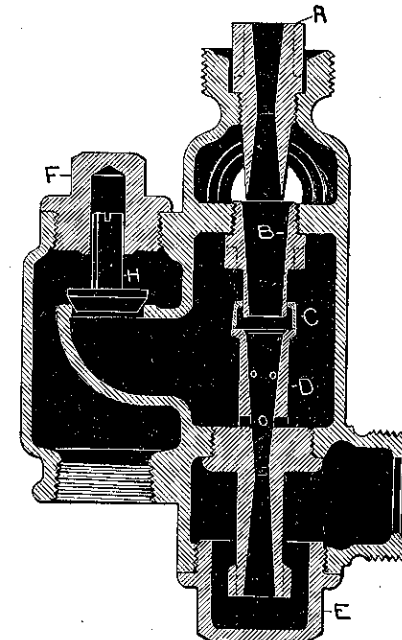
- 113 The manufacturers claim that this arrangement of valves gives the injector greater range and enables it to handle hotter water without losing the automatic principle.



Penberthy Auto Positive Injector. Fig. 92.

- 114 The Chicago Injector, made by the Ohio Injector Co., differs from the Penberthy in having a vertical check valve on the overflow pipe and a ring C between the suction and delivery jet that seats with gravity instead of against it. The advantage claimed for this arrangement is that a

sudden shock or jar only seats the ring more securely and the injector is not so apt to break in going over rough roads in consequence. This injector is shown in Fig. (93).



The Chicago Injector. Fig. 93.

- 115 The United States Injector, illustrated in Fig. 94, is shown fitted with a drip cock at the bottom for draining, which makes it especially desirable in the colder sections of the country where all pipes and connections must be drained at night during the late fall to prevent them from

freezing and bursting. This feature, however, is found on other makes of injectors, as well as on the one illustrated.

- 116 Besides the injectors above illustrated there are quite a good many others in common use, which, while they may differ in minor details, are similar in general construction to the ones shown.
- 117 *The Range of Injectors.*—The difference between the lowest steam pressure at which an injector will start and

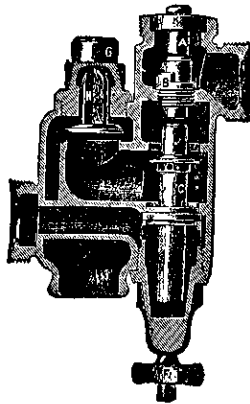


Fig. 94.

the highest at which it will work, constitute what is known as the range of an injector. These limits are affected by the vertical lift and the temperature of the feed water. This is well illustrated in the following statement of the performance of a well-known make of injector used widely

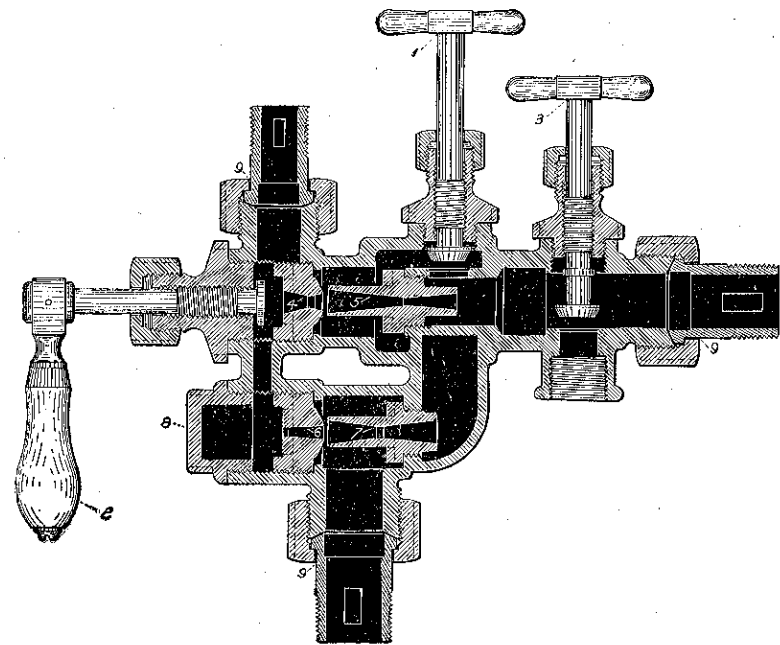
on traction engines. It will start with a steam pressure of 15 pounds per square inch on a two foot lift, with feed water at a temperature of 60 degrees, and will continue to work until the pressure reaches 155 pounds. However, if the lift is increased to 15 feet and the temperature to 100 degrees, it will require a pressure of 45 pounds to start with, and stop working when the pressure reaches 70 pounds; thus showing that the range is vitally affected by the working conditions.

- 118 Injectors used for traction engines usually start at from 25 pounds to 50 pounds and work up to 175 or 200 pounds. There are special injectors on the market that will start with steam at one pound pressure on no lift and others that will work up to 300 pounds, but where the starting point is so low the upper working pressure must be lowered and likewise with very high working pressures the starting point is raised.

- 119 *Heating Effect.*—Since the feed water which passes through the injector condenses the steam, which forces it into the boiler, it becomes heated to a considerable extent; the exact amount depending upon the temperature of the feed water and the pressure of the steam. Ordinarily, feed water is heated up to 140 or 160 degrees, although by throttling the amount of water and using the maximum quantity of steam its temperature can easily be raised to 200 degrees. This heating of the feed water is a very desirable feature of the injector, inasmuch as the boiler is thereby relieved of the strains due to cooling when cold feed water is used. Independent pumps also heat the

feed water if the exhaust is turned into the suction chamber, but this practice is somewhat objectionable because the oil used in lubricating the pump is forced into the boiler, and most all authorities agree that it is not desirable to introduce cylinder oil into a steam boiler. Of course the amount thus introduced is relatively small and perhaps may in many cases be neglected. However, the fact remains that it is not considered good practice.

120 *Double Tube Injectors.*—Double tube injectors have a wider range and will deliver considerably hotter water to the boiler than single tube injectors. They are used quite extensively on locomotives, but, only to a limited extent on traction engines, probably for the reason that they are somewhat more complicated and difficult to operate than those with a single set of tubes. A sectional view of an injector of this type is shown in Fig. 95.



Double Jet Injector. Fig. 95.

121

- | | |
|--------------------|--------------------|
| 1—Relief Valve. | 6—Lower Steam Jet. |
| 2—Steam Valve. | 7—Lifting Tube. |
| 3—Overflow Valve. | 8—Cap. |
| 4—Upper Steam Jet. | 9—Couplings. |
| 5—Forcing Jet. | |

122 In order to start this injector, first open the overflow valve, then open relief valve 1, and the valve in the steam

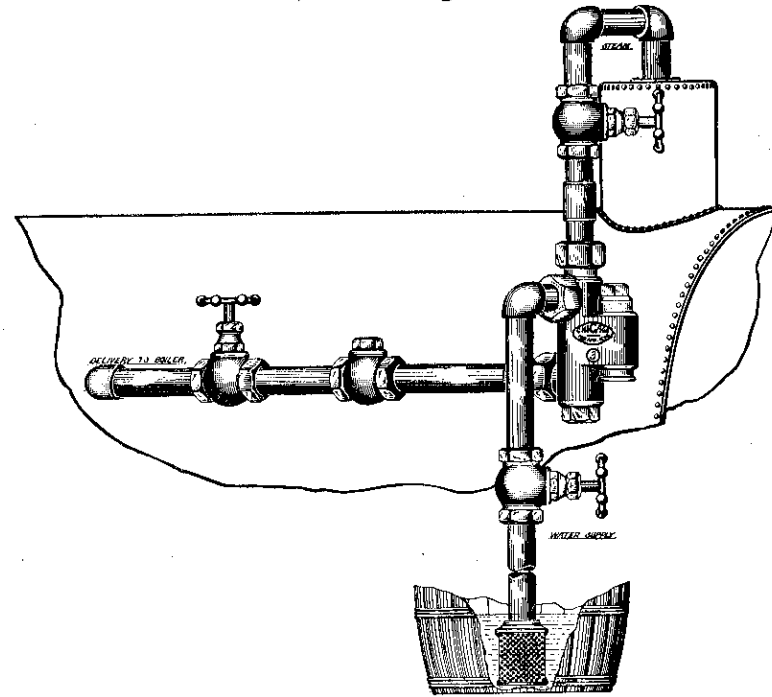
pipe; when water appears at the overflow, close relief valve 1, open the steam valve 2, and then close the overflow valve. The injector is now at work. In shutting down the injector, close the steam valve 2, then open valves 1 and 3 to drain the injector and then shut off steam from the boiler.

- 123 *Piping Up the Injector.*—The steam, suction, and delivery pipes must be of the same or greater size than the corresponding connection on the injector. They should be as short and direct as possible and sharp turns should, in general, be avoided. Steam should be piped from the highest point in the boiler because dry steam works much better in an injector than steam containing water. The valve in the steam pipe should be perfectly tight, otherwise steam will blow through and heat the injector, thus making it impossible to start; for the reason that the first water coming up the suction pipe will be turned into steam by the heat of the injector, thus destroying the vacuum. The only way to start an injector in this condition is to drench it with cold water until it is reduced to somewhere near the temperature of the feed water.

- 124 If the lift is high, either with a pump or an injector, a check valve should be placed at the bottom of the suction pipe. This check valve or foot valve, as it is commonly called, prevents water from running back into the tank and makes the machine easy to start the next time.

- 125 The necessary valves and connections for piping up an injector are shown in Fig. 96. Where the injector is to be used in a cold country it is better to use a water cock

instead of a globe valve in the delivery pipe close to where it enters the boiler, because a globe valve is apt to freeze



Piping Up an Injector. Fig. 96.

and crack. For the same reason the check valves should be provided with a drain cock.

- 126 *Injector Troubles.*—Injector troubles may all be divided into two principal classes; the first relating to the

suction and the second to the delivery of water to the boiler.

- 127 Among the first named troubles may be mentioned the following:
- 128 1—A steam pressure too low for the distance the water must be lifted. Few of the injectors used for traction engines will start with less than 30 or 35 pounds steam pressure and some require upward of 50 pounds.
- 129 2—The end of the suction hose out of the water. This seems so self-evident as almost to require no mention and yet many instances are on record where an expert has traveled many miles to find this the sole cause of failure. When the suction hose has lain in a coil for a long time previous to being used it has a tendency to coil up at the bottom and get out of the water unless weighted down.
- 130 3—A leak in the suction hose will cause trouble since even a small leak will impair the vacuum and make it impossible for the water to rise.
- 131 4—If the supply water is too hot the reduction of pressure in the suction hose caused by starting the injector will allow the water in the lower part of the hose to boil and form steam, thus destroying the vacuum. It will be remembered that it was shown on a previous page how a reduction of the pressure on water causes it to boil at low temperatures.
- 132 5—Wet steam is another condition that will cause an injector to fail, and is apt to be met with whenever the engine primes badly. The reason for failure in this case is due to the comparatively low velocity of a mixed stream of water and steam.

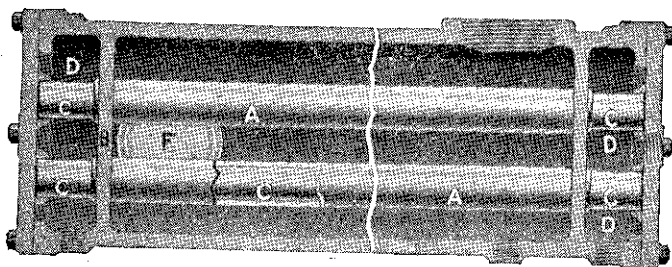
- 133 6—Chaff or dirt in the combining tube will cause the injector to fail, but this trouble is easily avoided by placing a strainer on the bottom of the suction hose, a precaution that should always be taken in threshing.
- 134 7—If the overflow valve is stuck shut, steam cannot blow out and exhaust the air from the suction pipe on first turning it on and consequently a vacuum cannot be obtained.
- 135 The second class of troubles, namely, the condition where the water rises to the injector but is not forced to the boiler, may be due to any of the following causes:
- 136 1—Low steam pressure, which is insufficient to give the volume of water which rises to the injector velocity enough to enter the boiler. It will be remembered that injectors are designed to work within a certain range and if the steam pressures are above or below the limits of this range the injector will not work.
- 137 2—A very small leak in the suction pipe will allow a mixture of air and water to reach the combining tube and will very frequently prevent the injector from working, because the stream flowing through the tubes is not purely liquid, but contains air which destroys the vacuum in the injector, thus opening the overflow and allowing water to escape therefrom.
- 138 3—If the check valve between the boiler and the injector is stuck the injector cannot work. The remedy for this is to tap the check valve lightly with a hammer, or better yet, close the globe valve between the check and the boiler, and clean it, after which it will probably work all right.

- 139 4—Either too much or too little steam, even of the right pressure, will cause the injector to fail. If too little steam is used the water will not have enough velocity to enter the boiler. If too much steam is used for the quantity of water, the stream passing through the jets will be partly gaseous and will not have enough momentum to enter the boiler. In the first case water will appear at the overflow; in the second, a mixture of steam and water.
- 140 5—Dirt or lime in the delivery pipe will prevent the injector from working. The tubes of the injector are proportioned each to the other and if one or two become partially filled with scale these proportions are destroyed, thereby causing the injector to fail. The remedy in a case of this kind is to take the tubes out and remove the scale by soaking them in vinegar or in a solution containing one part muriatic acid to ten of water. When the scale is removed, the injector should be washed thoroughly to remove all traces of the acid.
- 141 *If Water Drizzles from the Overflow* at the same pressure at which it once worked well it is due to worn or dirty jets or a leaky overflow valve. While an injector does not have many moving parts and is not very liable to wear with clean water, it is soon worn by water containing gritty sediment. This is especially true of the suction jet and the delivery jet since both of these jets receive the stream at a high velocity. The steam jet, which is acted upon only by the steam, is not liable to either wear or become coated with scale.
- 142 In case, therefore, that the injector drizzles at the over-

- flow an examination should be made of the overflow valve and its seat to see if it is worn or if there is any scale to prevent it from seating properly; if there is any trouble at this point it may be remedied by grinding the valve in with flour of emery. To do this remove the cap covering the valve, put oil and emery on the face of the valve and then turn it around on its seat a few times with a screw-driver.
- 143 In case the jets are limed they may be cleaned in the manner previously explained, if they are worn new ones should be put in. The delivery jet receives the most wear and consequently requires the most frequent attention.
- 144 *Feed Water Heaters.*—Quite a good many traction engines are provided with feed water heaters through which the feed water is pumped on its way to the boiler. These heat the feed water by means of the exhaust steam from the engine in a manner which will presently be explained. While the details of construction of different heaters differ from each other they are all built on the same general principle.
- 145 Fig. 97 is a sectional view of one style of feed water heater. It consists of a closed cylinder having double heads which form water tight compartments, shown at D at each end of the heater. Three tubes A, connect these compartments, making a water tight joint. The feed water enters one of the compartments and passes through the large tubes A, to the compartment at the opposite end. Smaller tubes C, are fixed within the large tubes A, making an annular ring about $\frac{1}{8}$ of an inch wide through which the water must pass. Exhaust steam from the engine enters

at the upper part of the middle compartment and passes out at F.

- 146 The result of this arrangement is to expose a thin sheet of water to the heat of the exhaust steam, thereby heating it to a temperature corresponding quite closely to the temperature of the exhaust steam. This temperature corresponds roughly to the temperature of steam at 5 pounds pressure, which is shown by the Steam Tables to be about 228 degrees. Of course in order to reach temperatures as high as this the water should be pumped through the heater



Feed Water Heater. Fig. 97.

slowly. If this is done, there is no trouble in raising the feed water to the boiling point, thereby effecting considerable saving in the amount of fuel and at the same time relieving the boiler from sudden cooling, due to the use of cold feed water. The amount saved by feed water heaters when an injector is used will be considerably less than when using either a duplex or a cross-head pump, because the injector heats the feed water to a considerable extent. Where a pump is used, whether of the independent or de-

pendent type, a feed water heater is desirable. In the case of the independent pump, by using a heater, it is not necessary to turn the exhaust steam into the suction chamber in order to heat the feed water, consequently no trouble will be experienced through oil being introduced in to the boiler.

- 147 One of the objections to a feed water heater in connection with a traction engine lies in the fact that the temperature, and consequently the pressure of the exhaust steam, is reduced, thereby impairing the draft to some extent. A drain pipe connected with the steam space is provided with all heaters and should be open when the engine is shut down to drain out the water of condensation which results from heating the feed water.

FEED WATER.

- 148 *Feed Water.*—The water used for traction engines is obtained from surface wells, artesian wells, rivers, creeks, lakes and sloughs, and consequently contains (in the majority of instances) a great many impurities. The character of these impurities depends, of course, upon the source from which the water is obtained. Water is one of the greatest solvents found in nature and almost every substance is dissolved by it to a greater or less extent, consequently, the impurities of the water will depend upon the mineral matter in the soil through which it flows. Water flowing through soil containing lime will be heavily charged

with lime. If it flows through alkaline soil the salts of alkali will be found in considerable abundance in the water.

- 149 The character of water for boiler purposes cannot be determined by its drinking qualities or by its general appearance. Some of the clearest sparkling spring water is most heavily charged with scale-forming substances. In general, lake water or river water is the best natural water to use. Water from deep wells usually contains a great deal of mineral matter unless it flows through granite rock, in which case it will be soft. Slough water usually contains whatever mineral impurities there are in the upper part of the soil, together with large quantities of vegetable matter which, as will be shown later, is very undesirable in feed water.

- 150 *Classes of Water.*—Water is usually divided into two classes—hard and soft. Hard water contains considerable quantities of lime, while soft waters, of which rain water is an example, contains very little mineral impurities.

- 151 *Incrustation.*—Incrustation is the name frequently applied to the hard scale which is formed inside of the boiler. It is formed by the precipitation of the mineral matter which is held in solution in the water. When water is heated most of the mineral matter will fall to the bottom and form a deposit on the tubes and lower part of the boiler shell. The steam which rises from water is almost pure and when condensed forms pure soft water, i. e., it contains no minerals; the mineral matter being left behind in the boiler.

If water containing large quantities of mineral matter is fed to a boiler for a considerable length of time a thick sheet of scale will form on the plates, because all the mineral matter of all the water fed to the boiler will remain therein, while the water will pass out through the engine as steam.

- 152 The substances which are most active in forming scale in boilers are carbonate of lime, sulphate of lime, carbonate of magnesium, sulphate of magnesium, and mud.

- 153 *Corrosion.*—Corrosion may be defined as the wearing or eating away of boiler plates due to chemical action. It is more active with some kinds of feed water than with others and depends upon the impurities of the water. Water containing alkalies are apt to cause corrosion of the boiler plates, especially around staybolts or rivets. Corrosion occurs either as a wearing away of the plate over its whole surface or in the form of pitting, where for some reason not yet explainable the plate becomes eaten away at some points more than others, forming little pits or indentations in the plate. Water containing acid causes corrosion, as will also the presence of animal or vegetable oils in the feed water. The reason oils corrode a boiler is that when heated to a certain extent they decompose, forming acids which attack the metal.

- 154 *Formation of Scale.*—The carbonates of lime and magnesium will not be held in solution to any extent when the water is heated to a temperature of 212 degrees F. When this temperature is reached these impurities settle to the bottom and form a grayish colored sediment which can

be washed out quite readily if no other mineral impurities are present. However, if sulphate of lime is also present in the water the resulting scale will be quite hard and difficult to remove. Sulphate of lime and sulphate of magnesium are soluble in water until it is heated to a temperature of from 250 to 280 degrees. When these temperatures are reached the sulphates are precipitated and settle to the bottom, forming a hard scale; the hardness depending somewhat upon the other impurities present in the water. Where considerable mud is present in the water, together with more or less lime, a hard scale will be formed. Mud alone does not usually form a hard scale unless it becomes baked on the sheets after the feed water is removed, a condition which is apt to arise if the water is blown out of the boiler under pressure, the heat remaining in the boiler plate being sufficient to bake the mud into a hard scale. In all cases scale forms on the boiler plate in layers, which are plainly discernible when the scale is broken up.

- 155 When mineral oil is introduced into a boiler it has a tendency to form around small particles of mud or scale and then settle to the bottom where it forms a tough rubber-like deposit which is very difficult to remove and which prevents the heat from passing through into the water. A thin coating of scale on the heating surfaces, say $1/32$ of an inch thick, is said by some authorities, to do no particular harm, but, on the contrary, protects the plates to some extent from corrosion. However that may be, it is certain that when scale forms to any appreciable depth, the steam-

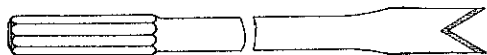
ing quality of the boiler is greatly impaired, and the danger from overheated plates is greatly increased. A comparatively thin coating of scale insulates the plate from the water and prevents the heat from passing through freely, allowing the side of the plate next the fire to become greatly overheated and softened. Most of the accidents due to a falling crown sheet or a collapsed main flue can be traced directly to a coating of scale on those surfaces. Accidents from this cause are especially liable to occur when an effort is made to raise steam quickly.

- 156 *The Removal of Scale.*—In large sized boilers the common way to remove scale is to send a man inside and have him chip it out with a hammer and chisel. Where the size of the boiler does not permit of such an operation, other means must be resorted to. In traction engine boilers which are small and rather difficult to get at, scale on the lower part of the shell is sometimes removed by means of a long-handled scraper which is worked through the handholes. It is impossible, however, by such means, to remove the scale from all of the flues.

- 157 Quite a common method of removing the scale is to fill the boiler nearly full of water, then introduce several gallons of kerosene and open the lower blow-off valve and allow the water to run out slowly. The oil will settle on the flues and sides of the boiler and soak into the scale. After standing for some hours a considerable portion of the scale, at least, can be jarred loose and washed out through the handholes. Another method is to drain the boiler and then build a light fire on the grates. The consequent ex-

pansion of the metal will crack a good deal of the scale loose after which it may be washed out after the boiler cools. Where this method is used care must be taken not to overheat the boiler.

- 158 A tool sometimes used for removing the scale from the crown sheets of locomotives is illustrated in Fig. 98. It consists of a bar of steel drawn down thin at one end and



Iron for Removing Scale. Fig. 98.

notched and sharpened. This notched end is very effective in removing the scale from around the staybolts. In many cases where trouble has been experienced with leaky staybolts in the crown sheet, the difficulty has been removed by cleaning off the scale with a tool of this kind. It is undoubtedly just as effective in cleaning the crown sheet of traction engine boilers.

- 159 *Prevention of Scale.*—In stationary plants and where large quantities of water is used, or at a watering station on the railroad where traffic is heavy and the amount of water used warrants the expense, it is sometimes found advisable to put up a water-purifying plant. Where this is done a chemist is put in charge of the station whose duty it is to analyze the water and put in the proper chemicals to effect purification. Since the amount of mineral impurities in the water changes from time to time, being greater at some seasons of the year than at others, it is necessary to vary the kind and quantity of chemicals used.

It must be understood that the matter of purifying water is a chemical rather than an engineering problem.

- 160 In traction engine work the kind of water used varies almost with every setting. Sometimes the water is gotten from a river, sometimes from a well, sometimes from a coulee, and consequently, the mineral constituents in each kind of water are usually entirely different. It becomes almost impossible, then, to resort to chemical means to purify the water with any degree of success. Probably the safest thing for the traction engineer to do is to depend upon frequent cleaning and a blowing off of a portion of the water every day, or even several times a day, where the water is very bad. Since the mineral impurities do not pass out with the steam, but remain in the boiler, it follows that the longer a boiler is used the more scale-forming materials there will be accumulated within, unless the percentage of these impurities is reduced by blowing off and by frequent cleaning.

- 161 *The Use of Kerosene.*—Many engineers use kerosene to prevent the formation of scale and find that it works quite successfully. Where kerosene is used it should be introduced with the feed water continuously in small quantities. Some injectors are on the market with a kerosene attachment whereby kerosene can be injected into the boiler whenever the feed water is introduced. Kerosene should be used sparingly, because it has a tendency to work into the joints and around staybolts, causing leaks to appear at these points; for this reason some authorities limit the amount to one pint per day for a 25 H. P. boiler.

- 162 The action of kerosene seems to be mechanical rather

than chemical in that it prevents the scale from forming a hard substance. It is supposed that the little particles of scale become coated with the oil and are thus prevented from adhering to each other when they settle on the boiler shell.

- 163 *Boiler Compounds.*—The base of nearly all boiler compounds consists of either soda ash, caustic soda, or tannic acid compounds derived either from catechu or the liquor from bark used in tanneries. These chemicals all act to a greater or less extent on the scale in a boiler and are possibly of some value for certain kinds of feed water.
- 164 Neither soda ash nor caustic soda are suitable for an alkali water, but tannic acid gives some relief. It is, however, dangerous to use as it corrodes the boiler badly unless used in exactly the right proportions, something that is impossible to do in traction engine practice.
- 165 Sodium triphosphate appears to give very good satisfaction in most cases, except where the water contains the alkalies, sodium carbonate or sodium sulphate, but it is rather expensive.
- 166 Some engineers report having had success with potato water, others recommend the occasional use of molasses, and still others think ground coffee aids in preventing scale. As a matter of fact, any of these substances will give relief with certain kinds of water but none are suitable for all conditions.
- 167 Glycerine is also recommended, especially for lime water.
- 168 There is a great deal of fraud practiced in connection with boiler compounds just as there is with lubricants and

many other supplies made up for the engineering trade. Some of the companies that advertise to make a chemical analysis of water sent for examination, agreeing to make up a compound to fit the individual case, simply consign the sample to the sewer and send along the regular goods, at the same time furnishing the customer with a stock analysis. There are, however, a number of reputable companies making boiler compounds whose goods may be depended upon.

- 169 The particular danger in buying a compound is in getting something not adapted to the water used that will do positive injury to the boiler.
- 170 Probably the least harmless substances to use are soda ash, kerosene, glycerine and the sodium phosphate compounds. None of them, as stated above, will correct the worst alkali waters; while soda ash and caustic soda will positively increase foaming in many cases.
- 171 *Alkali.*—In many parts of the West, certain alkalies are found in the feed water which gives the thresherman a great deal of trouble. These troublesome alkalies are sodium carbonate and sodium sulphate. While other scale-making substances, such as magnesium sulphate and magnesium carbonate, are, chemically speaking, also alkalies, and while they give considerable trouble in the way of forming a hard scale, they are not known commonly as alkalies. The action of the sodium carbonate, especially, and the sodium sulphate, to a less extent, is to make the water in the boiler foam very badly.
- 172 The greater the amount of these alkaline salts in the

water the more trouble there will be experienced through foaming. They, furthermore, it is said, act chemically upon the metal walls of the boiler, especially around the stay-bolts and joints, and cause corrosion at these points. If no other substance were present in the feed water, little difficulty would be experienced through scale, but when either of these alkalies are also found in the presence of lime or magnesium or muddy sediment, a hard scale results.

173 There seems to be no boiler compound which is safe to use, that will act upon these alkaline substances and prevent foaming. Any acid, it is true, will neutralize the alkalies, but the difficulty is to use just the right amount of acid for the quantity of alkali present. If too much is used, corrosion will occur very rapidly and the life of the boiler will be greatly endangered.

174 Probably the only method the thresherman has at his disposal for coping with these troublesome substances is to blow a portion of the water out of the boiler several times each day, thus keeping the percentage of the impurities in the boiler as low as possible.

175 *Foaming.*—Foaming is caused by alkali in the feed water or by dirt or grease in the presence of some other mineral impurities, such as magnesium, sulphate. Water obtained from ponds or sloughs containing considerable vegetable matter usually gives trouble by foaming. When a boiler foams the water level in the glass fluctuates very rapidly and the presence of bubbles makes it impossible to tell where the water actually is. At the same time a great many bubbles pass over with the steam into the engine,

causing considerable trouble by washing the oil from the valves and cylinder and causing danger to the cylinder by gathering ahead of the piston.

176 When foaming is caused by vegetable matter it may be relieved by a judicious use of the surface blow-off. Stopping the engine for a few minutes also allows the water to settle, or even partially closing the throttle and running slowly for a moment or two will give temporary relief. In all cases less trouble will be experienced by carrying the water as low in the glass as perfect safety permits.

177 *Priming.*—When water goes over with the steam into the engine the boiler is said to prime. An engine that primes appears to work hard, exhausts heavily, throws water from the stack, and usually makes a groaning noise in the cylinder. It may be caused by carrying the water level too high in the boiler, in which case the steam space is too small and the rapid flow from the steam pipe carries with it a fine spray of water, or, if the engine is overloaded, priming may occur because of the excessive quantity of steam required to do the work. A faulty adjustment of the valve is also said to cause priming in some cases.

178 A boiler will prime without foaming but foaming always causes priming. To stop priming, open the cylinder cocks, partially close the throttle, and let the engine run slowly until steam comes from the cylinder cocks.

QUESTIONS.

1. Why should a boiler be provided with at least two boiler feeders?
2. How much pressure does the air exert on every square inch? (b) Is this pressure constant, and if it varies, how does it vary?
3. What is the theoretical height to which water may be raised by atmospheric pressure?
4. Explain the action of a common suction pump; how does it differ from a force pump?
5. Why will not a pump lift hot water?
6. Define absolute pressure and state how it differs from gauge pressure.
7. How many and what classes of traction engine pumps are there? Name the pumps in each class.
8. Describe the water end of the Marsh pump.
9. What is the purpose of an air chamber on a pump?
10. Describe the cross-head pump.
11. Describe the duplex pump.
12. Upon what is the capacity of a pump dependent?
13. Explain how to locate the trouble in a pump if it fails to work.
14. Explain the theory of the injector.
15. What is the difference between an automatic injector and a positive injector?

16. What other devices work on the same principle as the injector?
17. What is meant by the term "range" as applied to an injector?
18. What effect has "lift" and temperature on the action of an injector?
19. About how much will an injector heat the feed water?
20. How do double tube injectors differ from single tube injectors?
21. Why is it that an injector will not lift hot water?
22. Mention the injector troubles relating to lifting of the water; those relating to forcing the water.
23. Describe the action of a feed water heater.
24. What impurities are found in feed water?
25. What is incrustation?
26. Name the substances most active in forming scale.
27. Why does scale form in a boiler?
28. What is corrosion and what causes it?
29. What effect has scale upon the steaming qualities of a boiler?
30. How is scale removed from boilers?
31. What means are usually taken for the prevention of scale?
32. Define foaming and explain how it may be prevented.
33. What is priming and how caused?

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PART V

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CLARKE SCHOOL OF TRACTION ENGINEERING

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PART V.

HORSE POWER OF BOILERS, MEASUREMENT OF BOILERS, COMBUSTION.

INTRODUCTION.

- 1 In the following pages a good deal will be said about heat and the heating value of different fuels, therefore, it seems advisable to explain briefly something about the nature of heat and why a study of heat is necessary to a complete understanding of the principles of steam engineering.
- 2 Heat is a form of energy and can be turned into work. A definite quantity of heat will produce a definite amount of work; consequently it is possible to express heat in terms of work or work in terms of heat.
- 3 The steam engine is primarily a heat engine, i. e., it depends upon heat for its motive power. It is a machine which transforms the energy of heat into the energy of motion, and that engine is the best which produces the largest quantity of work with the expenditure of the smallest quantity of heat.
- 4 The transformation of heat into work is a complicated process. The fuel is first burned in the furnace where it raises the temperature of the water in the boiler and forms steam which is piped to the engine and there does work. Numerous inevitable losses occur in the process, consequently only a small portion of the heat value of the fuel

HORSE POWER OF BOILERS, ETC.

is actually turned into work. It is commonly stated that ten tons of coal must be burned in order to obtain the work value of one ton, or, stated in another way, it means that 90 per cent of the fuel is wasted and only 10 per cent goes to do useful work. In traction engines the loss is even greater than this and probably amounts to about 94 or 95 per cent. Even in the very best engines that have ever been built, working under the most favorable conditions as to boiler plant and engine, the efficiency is very little above 20 per cent. This means that out of five tons of coal burned the heating value of only one has actually been transformed into useful work.

- 5 *The Character of the Heat Losses.*—Since heat is a form of energy it follows that any loss of heat means a loss of power, and since the losses are very great in a steam plant the question naturally arises, where do they occur and why can they not be obviated? These various losses may be classified as follows:—First, radiation from the boiler, engine and connections; second, a large amount of heat escapes into the atmosphere with the smoke; third, a large amount of heat escapes with the exhaust steam. The first loss cannot be entirely overcome, although it can be minimized by jacketing all of the parts carefully. It is one of the large losses. The second loss must always be reckoned with. It may be reduced in stationary plants by placing a coil of pipe in the smoke stack through which the feed water is pumped, thus making the heat of the hot gases heat the feed water, but even then the loss is considerable. The

third loss is always large and is inevitable, although it may be reduced somewhat by using a feed water heater.

- 6 *A Steam Leak.*—There is another source of loss about a good many steam engines and steam plants which does not come under any of the above headings, and that is leaky steam joints. Many engineers seem to think that a slight leak does not amount to very much and so they let it go. It is not uncommon to see an engine leaking steam so badly as to be almost hidden by the vapor and yet the engineer will sit by as complacently as you please and calmly tell you there is not much leaking out. The best way to test this statement is to lead a pipe from the steam space of the boiler, put a cap over the end of this pipe in which a small hole has been drilled, then condense the steam that escapes in a barrel of cold water. Weigh the barrel and water before turning on steam, then let the steam run ten minutes and weigh again. The difference will represent the weight of steam condensed. Now figure out at this rate how much would be lost in a day of ten hours and you will be convinced, once for all, that it pays to look after the small leaks.
- 7 A leaky union, a leaky throttle valve, or a part of the packing blown from under the steam chest cover or cylinder head may easily make it impossible to maintain steam pressure enough in the boiler to keep the engine running.
- 8 In order to discuss either boiler horse power or engine horse power it is first necessary to define work, energy and power.
- 9 *Work.*—Work may be defined as the overcoming of resist-

ance through distance, and the unit by which it is measured is called the *foot pound*.

- 10 Work may be expressed in foot pounds as the product of two factors, force and distance; for example, if a weight of 10 pounds be lifted 2 feet, 2×10 , or 20 foot pounds of work have been accomplished.
- 11 The term "*foot pound*" is equal to the amount of work involved in lifting one pound one foot high, or to the overcoming of a resistance or force of one pound through a distance of one foot.
- 12 In order that work may be accomplished it is necessary that the force act through some distance. A man holding a load on his shoulder is doing no work in the mathematical sense of the term, neither can the holding of a weight at arm's length be considered work since only one factor is involved, viz., force, and it does not act through any distance and so does not fulfill the definition of work. The man may become tired and feel as though he had done a great deal but whatever energy he has expended cannot be expressed in foot pounds. If a man climbs a stairs or walks up a hill, he performs a definite quantity of work, whose amount is equal to his weight multiplied by the vertical distance through which he moves. It requires work to haul a wagon along a level road, the amount of which depends upon the friction between the wagon and the road bed and the distance traversed. For example, if it requires a constant force of 50 pounds to keep the wagon in motion, and the distance passed over is 10 feet, the total amount of work done is 10 times 50 or 500 foot pounds.

13 *Energy.*—Energy is the power of doing work. It exists in many different ways. For example, a weight raised to a considerable height has a certain amount of energy due to its position, which may be turned into work if the weight be allowed to fall and strike an object. An example of this is seen in a pile-driver where the falling hammer strikes the head of the pile and drives it into the ground, thus doing work. A coiled spring, when either compressed or extended, possesses a certain amount of energy which may be caused to do work when the spring is released; likewise, the steam in a boiler under high pressure contains energy which may be turned into work when it is allowed to pass into the cylinder of a steam engine. Similarly a bullet fired from a rifle possesses a very great amount of energy, due to its high speed, which is capable of doing a large amount of work when forcibly brought to rest by striking an object.

14 There are two kinds of energy illustrated above, one due to position, and the other due to velocity or motion. In the case of the weight raised to a considerable height, its energy is due to its position and is called, technically, *potential energy*. In the case of the rifle ball, its energy is due to its velocity and is called *kinetic energy*. When the hammer of the pile driver begins to fall, its potential energy, or the energy due to position, decreases, and the kinetic energy, or the energy due to velocity, increases, until at the moment of striking, the potential energy is nothing, while its kinetic energy is a maximum. Thus it may be seen that bodies may possess both kinds of energy at one and the

same time and illustrates the fact that energy may be changed from one form into another.

15 The energy of the steam in a steam boiler may be changed in various ways. As an illustration, it may be transformed into the energy of motion of a moving train, and if the brakes be applied this motion may be arrested, and make itself evident in the form of heat on the wheels and on the rails, causing sparks to fly.

16 *The Law of the Conservation of Energy.*—It is a law of nature that matter can neither be created nor destroyed, although its form may be changed in numberless ways. To illustrate:—a piece of coal may be burned in a furnace and as coal it ceases to exist, but its elements have not been lost. If the ashes and all the gases of the coal which have passed off as smoke could be gathered together and weighed, their combined weight would exactly equal the weight of the original lump of coal. A piece of iron may be destroyed by rust and cease to exist in its metallic form, but it has only changed its form. There is just as much iron in existence before rusting began as after, only the iron has changed its form to iron rust or oxide of iron instead of being in the metallic form; and so numerous illustrations could be brought up to prove and illustrate the statement that matter can neither be created nor destroyed. Likewise, it is a fundamental principle of nature that energy can neither be created nor destroyed. Its form may be changed but the amount always remains the same.

17 A piece of coal has a certain amount of energy which may be set free in the form of heat when it is burned. This heat

may be changed into steam, and the steam be made to run a steam engine, which in turn drives a dynamo and produces an electric current which may be retransformed into heat in an electric heater. In this operation the energy of the coal has been changed in various ways, from heat to electricity, and back again into heat, and if all of the losses through radiation and leakage could be accounted for and added to the final energy of the electric heater, it would be found to exactly total the original energy in the coal. This principle, called the Law of the Conservation of Energy, has perhaps had more influence upon science and invention, since its discovery, than any other one fact that has ever been established. To state it in a perfectly plain, simple manner it means that you cannot get any more energy out of a machine than you put into it, in fact, it is impossible to obtain quite as much because some work is needed to overcome friction in the machine itself. Consequently, it is impossible to ever build a perpetual motion machine, because, in order to run forever the machine would be obliged to create its own motive power, a condition which is manifestly impossible, if the law be true.

- 18 *Power.*—Power is the measure of the rate at which work is accomplished. In all discussions of power three factors are involved, *force*, *distance* and *time*. The time is an important matter and must appear in all discussions concerning power but does not enter into the consideration of work. If two men are at work and one does twice as much as the other in the same length of time, the one exerts twice as much power as the other.

- 19 *Horse Power.*—The term "horse power" represents the accomplishment of 33,000 foot pounds of work in one minute. If a weight of 33,000 pounds be lifted one foot high, or a force of 33,000 pounds be exerted through a distance of one foot, 33,000 foot pounds of work will be done and if this work be done in one minute, it will be equal to a horse power. The amount of force exerted may be much less than 33,000 pounds, but if so, the distance must be greater than one foot; for example, a force of 1,000 pounds acting through 33 feet or 330 pounds acting through 100 feet both equal a horse power if the speed is sufficient to cover the distance in one minute.
- 20 Horse power is a definite mathematical unit used in measuring power and has absolutely nothing to do with the amount of work a horse may be able to perform. As a matter of fact, an ordinary horse working ten hours a day cannot do a horse power of work, although for a short length of time he may be able to accomplish considerably more than this amount.
- 21 *The term "Horse Power"* dates back to the early days of steam engineering. When James Watt put his steam engines on the market he found it necessary to designate their capacity for doing work in some way that would be understood by the average man, and so he compared the work of his engine with the work which the large London dray horses could do. These horses he found did an average of about 33,000 foot pounds of work per minute, and this was the unit adopted by Watt and which has been retained by steam engineers until the present day. An engine or an

animal that can do 33,000 foot pounds of work in one minute is capable of doing a horse power of work.

- 22 *Boiler Horse Power.*—The term horse power as applied to a steam boiler is an unfortunate term and does not convey any very definite idea concerning the size of a boiler, since the boiler does not work in the sense above described; i. e., it does not overcome any resistance through a distance and its performance, consequently, cannot be measured in foot pounds. The term, however, has been used for a great many years and is still in general use. At first it meant that a boiler of a certain horse power was capable of supplying energy for an engine of the same power. Later, when engines were built that required much less steam for the same amount of work, it was recognized that the term "boiler horse power" meant nothing.

- 23 In 1876 a committee appointed by the American Society of Mechanical Engineers met in Philadelphia and measured the amount of steam which was required per horse power per hour in the average engine and used this as their basis for figuring boiler horse power. They found that 30 pounds of water evaporated into steam at 70 pounds pressure, starting with feed water at 100 degrees, represented the average amount of steam required to do a horse power of work per hour. They thereupon decided that any boiler which could furnish this amount of steam, or its equivalent, represented a boiler horse power.

- 24 Or, stated in another way, they defined a boiler horse power as the evaporation of $34\frac{1}{2}$ pounds of water into steam at atmospheric pressure in one hour from feed water

at a temperature of 212 degrees. This quantity represents the expenditure of exactly the same amount of heat as required under the other conditions, where 30 pounds of water is specified.

- 25 As will be seen from the above description, the term "boiler horse power" is not directly connected with the amount of work an engine is able to do but simply relates to the evaporation of a certain quantity of water per hour. Some engines require a good deal more than this amount of water per horse power per hour, while some of the small, cheap engines take upwards of 100 pounds. The ordinary traction engine probably uses about 30 or 35 pounds per horse power per hour, making the term "boiler horse power" apply about as closely to these engines as to any on the market.

- 26 *The Capacity of a Boiler to Generate Steam.*—It was shown above that the power of a boiler depends upon the amount of steam it can generate in a given length of time. It should also be further specified that the boiler must generate this steam under ordinary normal working conditions as regards firing and with a good ordinary grade of coal. It is perfectly possible by using a high grade coal and firing hard to crowd a boiler much beyond its ordinary rated capacity. It is not uncommon for boilers to be thus crowded from 50 per cent to 100 per cent above their rating; thus it will be seen that boilers, as rated, have a considerable amount of reserve power, a condition which is quite desirable in all classes of machinery.

- 27 *Rated Horse Power vs. Actual.*—The term horse power

as applied to a traction engine is perhaps more confusing than instructive. Very frequently one hears the remark that a certain engine of, let us say 25 horse power, is stronger than another engine of exactly the same rating, and it frequently happens that the statement is perfectly true. However, if both machines actually were 25 horse power there could be no difference in their strength, since a horse power is a perfectly definite thing and one horse power cannot be greater than another. The reason for such statements is the fact that all traction engine builders do not rate their engines on the same basis. There are, perhaps, no traction engines built in this country which are not under-rated a great deal and some much more than others. Engines commonly rated at 25 horse power will easily develop 50 horse power on the brake, and some of them will develop upwards of 75 horse power. The only way, therefore, to determine the relative sizes of engines and boilers is to compare their measurements. Two engines having the same sized cylinders, working with the same steam pressure, and running at the same rate of speed will develop practically the same horse power, and two boilers of the same type, having similar measurements thruout, ought to develop the same amount of boiler horse power. If one is larger than the other thruout, it ought to develop more horse power, irrespective of how it may be rated.

- 28 The reasons for under-rating traction engines are, first, the necessity of providing for a large amount of reserve power on account of the varied service required of engines of this class which often call for an expenditure of two or

even three times the normal amount used; and second, the desire of many manufacturers to outdo their competitors by building a rig of the same rating having considerably more power.

- 29 In consequence of these two reasons the result has been, as stated above, that the term horse power applied to traction engines means very little. Many people who have replaced steam rigs with gasoline rigs in the past few years have found this out to their sorrow. Most gasoline engines are rated according to their actual horse power, altho, at the present time, those manufacturers who are building traction engines are under-rating their machines. Because of the fact that the gasoline engine was rated according to actual horse power, men who bought 20 or 25 horse power engines expecting them to do the work of steam engines of the same rating were greatly disappointed. As a matter of fact, while they were getting exactly the same rating they were only getting from one-third to one-half as much power as they had in steam.

- 30 *Horse Power Based on Heating Surface.*—The capacity of a boiler to make steam depends upon the amount of heat generated in the furnace and the proportion of this heat which is transferred to the water. The amount of heat generated depends upon the amount of fuel burned, the quality of the fuel, and the size of the grate. The proportion of heat transferred to the water depends upon the arrangement of the heating surface and the ratio of grate surface to heating surface. Each type of boiler has certain proportions which experience has shown to give good re-

sults for that particular type. While these proportions are not followed rigidly by all of the different manufacturers, either of stationary boilers or of traction boilers, still only a few very marked deviations occur.

- 31 The following table which is taken from Peabody and Miller's "Steam Boilers" shows, in column three, the number of square feet of heating surface usually allowed per boiler horse power in different styles of boilers.

Table I.

Lancashire	25 to 30	.36	7.0
Cylindrical Multitubular ..	35 to 40	.30	11.5
Locomotive	60 to 70	.07	4.5
Locomotive type, Stat'y. ..	40 to 45	.30	12.6
Scotch Marine	30	.11	3.3
Water tube with cylinder or drum	35 to 45	.28	11.0

- 32 A study of this table shows wide variations among the different types of boilers in regard to the amount of heating surface required for the same amount of power. When worked under favorable conditions each of the different types mentioned in the table will give good efficiency and will evaporate the same amount of water with practically the same amount of fuel.
- 33 A comparison of all the different makes of direct flue traction engine boilers shows that they possess 11 1-3 square

feet of heating surface per rated horse power, which is an amount about equal to that specified for cylindrical multitubular boilers. Return flue traction boilers show a slightly smaller average amount of heating surface than the direct flue type, the average for quite a large number being about 10.

- 34 *Horse Power Based on Grate Surface.*—Column two of Table I shows the number of square feet of grate surface per rated horse power. Here again there are very wide differences, ranging from .36 of a square foot in the Lancashire boiler to only .07 of a square foot for locomotives.
- 35 For ordinary stationary boilers of the multitubular type it is customary to divide the total grate area in square feet by one-third to determine the horse power. Traction engine boilers of the direct flue type show an average grate area per rated horse power of .424 of a square foot; an amount which is considerably in excess of any of the boilers mentioned in the table. The rated horse power of traction engines can be approximated quite closely by dividing the total grate area by .4. The quotient will be a little high for some makes of engines and a little low for others.
- 36 These averages of grate surface and heating surface are interesting when taken in comparison with the locomotive, which is perhaps the nearest relative to the traction engine. Where the locomotive has .07 of a square foot of grate surface, the traction engine has six times as much, and where the locomotive has $4\frac{1}{2}$ square feet of heating surface, we find the traction engine provided with almost three times that amount; facts which apparently show that the

traction engine boiler is very much under-rated or else that the locomotive is over-rated.

- 37 *Measurement of Heating Surface.*—In direct flue boilers the heating surface consists of the walls of the firebox—not counting the parts below the grates—together with the internal area of the flues, and that much of the front flue sheet not occupied by the flues. From this total there must be subtracted the openings for doors in the firebox together with the combined area of the openings cut in the rear flue sheet for the flues.

- 38 The heating surface in a firebox may be found as follows: Multiply the width by the height and this product by 2, the result will be the heating surface in the ends of the firebox; from this quantity subtract the area of all the flues and the fire door and draft door openings, the remainder will be the actual surface. Then multiply the height of the firebox by its length and this product by 2, to find the heating surface of the sides. The area of the heating surface in the crown sheet is equal to the width of the firebox multiplied by its length. The total area of the firebox, therefore, will be equal to the sum of the three quantities above found. In order to find the heating surface in the flues, first find the circumference of one flue and multiply this by its length (both quantities should be expressed in inches), the product will be the number of square inches of heating surface in the flue. This multiplied by the number of flues will give the total heating surface in the flues. To this add the area of the front tube sheet after subtracting the combined area of the openings cut out for the flues.

The sum of the heating surface in the firebox expressed in inches, plus the heating surface in the flues expressed in inches, equals the total number of square inches of heating surface in the boiler. If this quantity be divided by 144, the result will be the total heating surface of the boiler expressed in square feet.

- 39 *Example.*—Find the number of square feet of heating surface in a direct flue boiler whose dimensions are as follows: Height of firebox 42-inches, width 30-inches, length 44-inches, having one fire door 10 × 12 inches and one draft door 4 × 6 inches. Diameter of shell of boiler 36-inches. Number of flues 52, length 100-inches, diameter 2-inches.
- 40 *Solution.*— $30 \times 42 \times 2 = 2520$, the number of square inches in the ends of the firebox.
- 41 $30 \times 44 \times 2 = 2640$, the area in square inches of the sides of the firebox.
- 42 $44 \times 42 = 1848$, the area of the crown sheet.
 $2520 + 2640 + 1848 = 7008$, the total area of the firebox, making no allowance for openings.
- $10 \times 12 = 120$, the area of fire door.
 $6 \times 4 = 24$, the area of draft door.
- 43 Now to find the area of the openings cut for the flues find the area of each hole and multiply by 52 the number of holes.
- 44 The area of a circle equals one-half the diameter or the radius multiplied by itself and this product multiplied by 3.1416, therefore we have in this case
 $1 \times 1 \times 3.1416 = 3.1416$, the area of one flue hole.
 $3.1416 \times 52 = 163.36$, the area of all flue holes.

$120 + 24 + 163.36 = 307.36$, the area of all openings in the firebox.

45 $7008 - 307.36 = 6700.64$ sq. in., the actual heating surface in the firebox after taking out all openings.

46 The circumference of a circle may be found by multiplying the diameter by 3.1416; therefore,

$2 \times 3.1416 = 6.2832$, the circumference of a flue.

$6.2832 \times 100 = 628.32$ sq. in., the area of one flue.

$628.32 \times 52 = 32627.64$ sq. in., the total heating surface in the flues.

47 $3.1416 \times 18 \times 18 = 1017.87$ sq. in., the area of the front tube sheet.

48 $1017.87 - 163.36 = 854.51$, the area of the flue sheet after making allowance for the openings cut out for the flues.

6700.64 — the area of the firebox,

32627.64 — the area of the flues,

854.51 — the area of the front flue sheet,

40182.79 — sq. in., the total heating surface in the boiler.

49 $40182.79 \div 144 = 279.04$ sq. ft., total heating surface in the boiler.

50 $279.04 \div 11.33 = 24.6$ or practically 25 as the rated horse power of the boiler above figured.

51 *Boiler Efficiency.*—It is customary to compare the performance of different boilers on the basis of the number of pounds of water evaporated per pound of fuel burned; that boiler being the best which shows the largest amount

of evaporation per pound of fuel. The very best boilers, using a good grade of coal, show an evaporation of about 12 pounds of water per pound of dry coal. This evaporation is figured on the basis of feed water at temperature of 212 degrees and the resulting steam at atmospheric pressure.

52 Ordinary boiler performance with a good grade of soft coal shows an evaporation of seven or eight pounds of water per pound of coal, taking the coal as it runs. Lignite does not show as good results since it only evaporates about $2\frac{1}{2}$ or 3 pounds of water per pound.

53 In order to compare the performance of different boilers it is necessary to test them under exactly similar conditions or else to take into account the conditions in each case and make the proper allowances which will make the conditions similar in effect. In consequence of this necessity for similarity, it is customary to reduce the results of the test to a standard known as *equivalent evaporation*. In this standard the feed water is assumed to be at a temperature of 212 degrees and the water is evaporated into steam at atmospheric pressure. Theoretically, one pound of coal will evaporate about 15 pounds of water, but in practical work it is not usual to obtain an evaporation greater than about $11\frac{1}{2}$ or 12 pounds, and in traction engines exposed to outdoor conditions where the radiation is often very high, results as high as these are not often obtained. On the basis of 15 pounds theoretical evaporation, and 12 pounds actual, the efficiency of a boiler is $12/15$, or 80%.

In a few instances a slightly higher efficiency has been recorded, but in the majority of cases few boilers are able to yield much more than 60 or 70% efficiency, i. e., out of 100% of heat which is put into them in the form of fuel only 60 or 70% can be accounted for in the steam.

54 *Inevitable Losses.*—In the best boilers there is a loss of heat of about 20% and in ordinary boilers, which undoubtedly include traction engines, the losses range anywhere from 30 to 50%. The question naturally arises, where do the losses occur and why are they not prevented? A complete answer to this question involves a discussion of the laws of heat which are beyond the limits of this part of the work and only a brief outline can be given.

55 A considerable amount of heat is lost thru radiation to the outside air and some in heating the metal work of the boiler, but by far the greatest loss is due to the hot gases which pass up the chimney. In ordinary boiler plants the temperature of the chimney gases, as they leave the boiler, is in the neighborhood of 500 degrees. In the case of traction engines, working with strong induced draft, the temperature in the stack runs as high as 600 or 700 degrees.

56 It requires about 24 pounds of air for every pound of coal burned and all of this air, together with the resulting gases of combustion, absorbs a large amount of heat in the furnace and gives up a considerable portion to the heating surface on its way thru the boiler, but as previously stated, a large amount passes out thru the stack into the atmosphere. This loss of heat thru the chimney is the greatest single loss in boiler practice and even under the

most favorable conditions amounts to a large proportion of the fuel. There seems to be no way to prevent this loss of heat, altho in some stationary boilers it is minimized by being made to heat the feed water.

57 *Testing Boilers.*—In view of what has been said it will readily be understood, that, in order to test the performance of a boiler, it is necessary to weigh the amount of coal burned and the amount of water pumped into the boiler in a given length of time. Then, in order to reduce this to the standard of equivalent evaporation, the temperature of feed water and the pressure of steam in the boiler must also be known. It can then readily be determined how many pounds of water have been evaporated per pound of coal. In making a complete boiler test other conditions are also taken into account, such as the temperature of the air surrounding the boiler, the amount of ash in the coal, and the numerous other things which have a bearing on the test.

COMBUSTION.

58 Combustion or the burning of fuel is a chemical process in which the carbon of the fuel unites chemically with the oxygen of the air to form a new chemical compound, carbon dioxide. In this process, as is the case in all chemical reactions, the process is accomplished by the setting free of heat. Since oxygen is a necessary element in combustion, it follows, that to get the best results, the draft must be right to supply the requisite amount of air for the amount of fuel burned.

- 59 Air consists of one part of oxygen to four of nitrogen. The nitrogen does not aid in combustion and is one of the reasons for the great loss of heat through the escaping gases, since this nitrogen must be heated up to the temperature of the fire and passes out of the chimney still carrying considerable heat. On account of its presence the amount of gases passing out of the chimney is very large and consequently the heat loss is proportionately large.
- 60 Theoretically, only 12 pounds of air are required to burn a pound of coal, i. e., there is enough oxygen in 12 pounds of air to combine with the carbon of the fuel and effect complete combustion, but since it is impossible to bring all of the oxygen of the air in contact with all of the particles of burning fuel, the amount of air required runs anywhere from one and one-half to two or three times this amount. When the combustion of carbon is complete two atoms of oxygen unite with one atom of carbon, forming what is known as carbon dioxide. If there is not enough oxygen supplied for complete combustion only one atom of oxygen unites with one atom of carbon, forming what is known as carbon monoxide. In the first case, where combustion is complete, the resulting temperature and consequently the amount of heat set free is the maximum, while in the second case the amount of heat set free is only one-third as much. If carbon monoxide can be exposed to high enough temperature in the presence of fresh oxygen, it will unite with more oxygen, forming carbon dioxide, and the other two-thirds of the heat will then be set free. It is partially on this account and partially because when fresh coal is thrown

- in, certain other combustible gases arise from the coal, that it is found advisable to admit air into the firebox at the upper part of the brick work, thus igniting those gases and causing them to burn above the brick work, which otherwise would pass thru the flues and out thru the chimney unconsumed, thus causing a considerable loss of fuel and consequent loss of efficiency of the boiler.
- 61 In addition to the carbon in coal there are certain other combustible substances usually present in soft coal and lignite, called hydro-carbons. These form the volatile or gaseous part of the fuel and are driven off when the temperature of the coal rises nearly to the kindling point. When fresh coal is thrown into the furnace, these gases rise and if the temperature in the firebox is not sufficient to ignite them they pass out of the smoke stack unconsumed.
- 62 *Kinds of Fuel.*—The fuels used for traction engine work vary with the different sections of the country. The principal fuels are soft coal, straw, oil, lignite and wood; the most important for traction engine work being the first three mentioned. Coal is used in nearly all sections of the country; straw, mainly in the Northwest; oil, in the Southwest and on the Pacific Coast; lignite, to a limited extent, in numerous western states; and wood, in the newer wooded sections of the country.
- 63 Soft coal is used more widely than any of the other fuels for the reason that it is generally easy to obtain and gives good satisfaction. Each of the different fuels mentioned possesses different heating values per pound of fuel. A pound of oil, for example, possesses more heating value

than a pound of coal or wood, and a pound of coal contains more heat than a pound of straw or of lignite.

- 64 *Heating Value of Different Fuels.*—The heating value of a fuel depends upon the amount of carbon and hydro-carbons which it contains and also upon the amount of ash and moisture in the fuel. A pound of pure carbon contains 14,500 heat units, i. e., it contains heat enough, if this heat could all be utilized, to heat 14,500 pounds of water one degree. Ordinary soft coal has not as high a heating value as this, owing to the fact that it contains some moisture and a considerable quantity of incombustible matter which forms the ash in the fuel.
- 65 Analyses of various soft coals show that their heating value ranges in the neighborhood of 13,000 heat units. Crude oil has a higher heating value than any of the other fuels mentioned, ranging from 19,000 to 22,000 heat units per pound; thus one pound of oil is equal to about 1.8 pounds of good soft coal. Straw has a relatively low heating value but it is used extensively nevertheless, because it is easy to get and being of no commercial value on most of the western farms its cost may be considered zero, whereas coal, in the same locality, costs from \$7.00 to \$10.00 per ton, depending upon distance from the mines.
- 66 Different kinds of straw have different heating values; for example, wheat straw contains about 5500 heat units while flax straw has between 7,000 and 8,000, or a little better than half the heating value of good soft coal. All who have fired with straw have noted that it was much easier to keep up steam with flax straw than with any other, and

the reason is plainly evident when the heating value of the different kinds of straw is compared. Oat straw and Macaroni wheat straw have a lower heating value than either wheat or flax straw. Where a pound of soft coal will evaporate say 8 or 9 pounds of water per pound of fuel, flax straw will evaporate about 5, and wheat straw between 2 and 3½.

- 67 The heating value of lignite varies widely with the mine from which it is taken or even from different parts of the same mine. As a rule, lignite does not run as uniformly in quality as soft coal. It usually contains from 20 to 30% of moisture which reduces its heating value considerably since this moisture must be evaporated in the firebox at the expense of the combustible portions of the coal. It also contains from 10 to 15% of ash, thus leaving only about 60% which can be burned; consequently, its value as a fuel does not run any higher than straw; in fact, numerous tests which have been made show that a pound of lignite will evaporate only between 2 and 3 pounds of water.
- 68 The value of wood is considered to be equal to .4 that of coal, i. e., it requires 2½ pounds of wood to equal one pound of good soft coal. Pound for pound, one kind of wood has about the same heating value as another, altho so far as ease in handling and keeping up the fires are concerned, the harder woods appear to have considerable advantage.
- 69 *The Firing.*—Different kinds of fuel require different methods of firing in order to get the best results. While

a great many people seem to think all that is necessary is to shovel in the fuel and that anybody will do for a fireman, the facts of the case are that in order to get the best results a great deal of care and judgment must be exercised in firing and the service requires a good intelligent man.

70 In many cases where trouble is experienced in keeping up steam, the difficulty is not with the engine nearly so much as it is with the fireman. If he takes care of the parts entrusted to his care and keeps his fires in good condition and uses the proper judgment in all cases, little difficulty is usually experienced in keeping up steam. A man who has been used to firing with coal will usually have considerable difficulty with straw or with lignite, since both require quite different treatment. In order to discuss the subject of firing to the best advantage it will be necessary to take up in detail the method of handling the different kinds of fuel.

71 *Starting the Fire.*—When coal is used for fuel the fire must be started with wood or shavings until high enough temperature is reached to ignite the coal. First, make sure that there is plenty of water in the boiler, then start a brisk fire with wood shavings or kindlings, and add coal, gradually, until all parts of the grate are covered evenly with a thin bed of coals. The blower may be turned on when the steam pressure goes up to about 20 or 25 pounds, but not before. After the engine is started, the blower should be turned off, as the exhaust will furnish sufficient draft for the fire.

72 *Firing with Coal.*—Coal is rather difficult to fire with and requires considerable experience to get good results. A poor fireman can easily waste a large amount and still not get as much steam as the boiler is capable of furnishing. To be effective, the fire should be thin and evenly distributed over the grates, taking care that no holes or dead places appear.

73 Air follows the course of least resistance and is sure to pass up thru any open space there may be in the fire instead of thru the fire as it should. From 4 to 5 inches is the right thickness for the fuel, if soft coal is used. The coal, no matter what kind is used, should be broken into pieces not larger than the two fists in order that it may lay together closely and form a thin even bed over the grates. If large lumps are used they leave too many open spaces in the grates thru which the cold air may pass and the result is a poor fire.

74 Do not stir the fire more than enough to keep it free from clinkers and ashes. It is occasionally necessary to run the poker under the fire to get rid of ashes or in some kinds of coal to break up the clinkers. Whenever this is done the fire will die down to some extent and it is best to perform this operation on a rising steam pressure or at least when the steam pressure is high; because if the pressure is falling, the cleaning of the fires will reduce the temperature in the firebox and make the pressure fall still lower before the fires can be replenished.

75 Try to keep the dampers open a uniform distance all the time and regulate the amount of steam by the coal used,

and the draft. The steam pressure should be maintained just a little below the blowing off point in order to get the best results from both the engine and the boiler. A change in the steam pressure means a change in the temperature of the whole boiler also and this causes either contraction or expansion which is apt, eventually, to cause leaky joints.

76 *System in Firing.*—To do the best work and get the best results in firing, it is well, especially for a beginner, to follow a system in placing the coal so that it will be spread evenly over the grates. If the coal is thrown first in one corner and then in another, and so on around, with a shovelful in between, and this rotation followed every time, it will be easy to keep an even thickness of coal on the grates. Between each shovelful, close the door and wait until the next shovelful is needed. Always open the door quickly and close it again as soon as possible to prevent cold air from deadening the fire and striking the flues.

77 *Effect of Opening Fire Door.*—It will be observed that when the fire door is first opened, with a good fire on the grates, that the flames reach the top of the firebox, but in an instant after the door is opened the flame dies down, leaving a bed of bright coals on the grate, thus indicating a drop in temperature of several hundred degrees at least, with the consequent contraction of the metal which follows a sudden change in temperature. Never open the fire door and close the damper when the engine is running, because the exhaust will induce a heavy inrush of cold air over the

top of the fire, which will lower the temperature and cool the flues, thus causing them to leak.

78 *Firing with Straw.*—In firing with straw it is essential to keep the chute well packed with straw all of the time. By so doing cold air is prevented from getting in over the top of the fire and injuring the flues. Care should be taken, however, not to push the straw in too rapidly but just fast enough so that it may consume in the firebox before falling to the grates; in other words, the firebox should not be crammed with straw, too much straw will check the fire and spoil the draft. The proper way to do is to fire a small forkful at a time and fire constantly.

79 Three grate bars are usually sufficient for burning straw. These should be equally spaced in the firebox. The front part of the ashpan should be kept free from ashes to insure a free draft. The rear part of the grates is usually made blank by means of a dead plate. Where a dead plate is not used it is sometimes found advisable to allow ashes to pile up for about a foot under the rear of the grates to compel the air to pass forward and meet the incoming straw. The flame going over the baffle plates should appear white, as seen thru the side doors, and should not vary when the straw is pushed in.

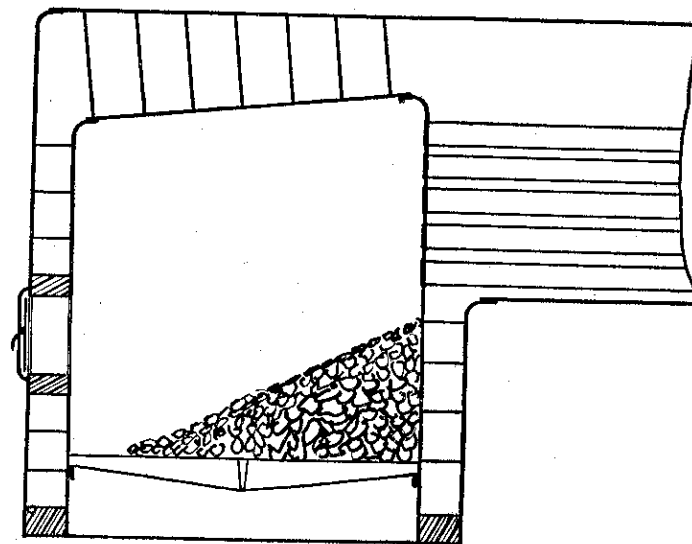
80 *Clinker in Straw.*—Straw forms a good deal of hard clinker, especially if it is a little damp, which, together with the ashes, must be removed frequently from the ashpan in order to provide an unobstructed draft. Clinker is also apt to form on the upper side of the baffle plate or arch and frequently clogs the flues, therefore, in firing with

straw, the fireman must be watchful to prevent the ends of the flues from becoming capped or clogged with clinker. Small side doors on the side of the firebox are provided in straw burning boilers, thru which a scraper may be worked for cleaning the ends of the flues.

- 81 *Firing with Lignite.*—The directions given for firing with coal apply with equal force to firing with lignite, with this exception, that a lignite fire must be somewhat thicker than a coal fire and must be watched more closely.
- 82 There is a great deal of ash in lignite which accumulates in the bottom of the fire and obstructs the draft. These ashes must be gotten rid of by cleaning the fires quite frequently. This is accomplished just as in an ordinary coal fire by running the poker down the grates underneath the fire. The proper depth for a lignite fire is about 8 inches, or almost twice that of an ordinary coal fire.
- 83 *Firing with Wood.*—In firing with wood the firebox should be kept well filled. If the wood is dry, it may be thrown in at random, but if green, it should all lay in the same direction. Moderate sized pieces will burn better and keep an even fire than very large or very small pieces. A green wood fire must be kept up to a high temperature all the time or it will not burn well. This is due to the large amount of moisture which green wood contains. It helps a wood fire to poke it occasionally, thus allowing the ashes to fall to the bottom.
- 84 In firing with any of the fuels above mentioned, care must be taken to keep ashes from underneath the grates; otherwise, the air cannot circulate around the under part

of the grates and keep them cool, a condition which is necessary in order to protect them from the intense heat of the fire. If grates burn out, as they frequently do, it is due in every case to the negligence of the fireman who has permitted ashes to accumulate in under them.

- 85 *Banking Fires.*—The proper way to bank a fire is to push all the fire and coals to the front end of the firebox up



Method of Banking a Fire. Fig. 99.

against the flue sheet, see Fig. 99; then, if desirable, fresh coal may be thrown on the top. What little air gets into the firebox will then pass over the fire instead of thru it,

causing it to burn from the top, and very slowly. In this way a dull fire can be maintained for quite a good many hours.

86 If the fires are banked in the evening they may be raked down the next morning and the boiler fired up in a very short time, because the firebox will still be warm and the water in the boiler will contain considerable heat. In cold weather it is especially desirable to bank the fires, thus preventing the pipe connections from freezing. A straw fire cannot be banked very easily, altho it is sometimes possible to do so with heavy chaff containing weed seeds.

87 If the fire is banked at night, make sure that there is plenty of water in the boiler, at least half a glass full, otherwise the water may be found dangerously low in the morning.

88 *Firebox Temperatures.*—Most everybody has observed that it is easier to start a fire in a warm furnace or in a warm stove than in a cold one. The reason why it is easier to start a fire in a warm furnace than in a cold one, is because the cold walls of the furnace absorb the heat from the fire so rapidly that the fuel is kept barely at the kindling temperature, while a warm firebox which does not absorb the heat so greedily, allows the fuel to become heated thru quickly, allowing it to burn readily. Any fuel, in order to burn, must be brought up to what is called the kindling temperature.

89 *Kindling Temperatures of Fuel.*—Coal will not burn until it reaches a temperature of 750 degrees Fah. Wood must be brought up to a temperature of 450 or 500 degrees,

and even kerosene to a temperature of upwards of 125 degrees Fah., before it will ignite. The theoretical temperature of combustion for coal is in the neighborhood of 5,000 degrees, but owing to radiation and the necessary excess of air to provide sufficient oxygen, this temperature is never reached in practice.

90 A long series of tests on the temperature of combustion in locomotive fireboxes at the World's Fair at St. Louis, in 1904, showed temperatures ranging from 1,350 to 2,300 degrees, with an average of about 2,000 degrees for firebox temperatures. In traction engine boilers it is probable, altho no authentic tests are on record, that the average temperature lies between 1,800 and 2,000 degrees.

QUESTIONS.

1. Define heat.
2. Upon what does the steam engine depend for its motive power?
3. In ordinary engines how much of the heat value of the fuel is lost?
4. In what way is heat lost in a steam power plant?
- (b) Can these losses be entirely overcome?
5. Define the following terms: Work, foot pound, energy.
6. If a ton of hay is lifted from the ground into a barn 20-ft. high, how many foot pounds of work is done?
7. State examples of potential energy and of kinetic energy.
8. Explain the Law of the Conservation of Energy.
9. What is power and what three factors enter into all discussions of it?
10. Explain the term "horse power."
11. What is meant by boiler horse power?
12. A boiler is capable of evaporating 6,000 pounds of water per hour, "equivalent evaporation." What is the power of the boiler?
13. A certain hoisting engine lifts 7,250 pounds of ore from a mine 210-ft. deep every minute. What is the horse power of the engine?
14. A horse traveling at the rate of three miles an hour

pulls a load which requires a force at the draw pin of 42 pounds. How much horse power is the horse exerting?

15. In what way should traction engines be compared in regard to power?

16. A traction engine boiler contains 287 sq. ft. of heating surface. About what is its rated horse power?

17. State how to measure the heating surface in a direct flue boiler.

18. Find the number of square feet of heating surface in a direct flue boiler whose dimensions are as follows: Height of firebox 44 inches, width 32 inches, length 46 inches, having one fire door 10x12 inches and two draft doors, each, 4x6 inches. Diameter of shell of boiler 40 inches, number of flues 60, length of flues 108, diameter 2 inches.

19. What is meant by the term "boiler efficiency"?

20. Mention the inevitable losses of heat in boiler practice.

21. Explain what is meant by combustion.

22. Why is air sometimes admitted above the fire?

(b) Is this practice to be commended?

23. Explain how to fire with coal.

24. Why do grate bars burn out?

25. Explain how to bank a fire and state the object of banking fires.

26. What is meant by the term "heating value" as applied to fuel?

27. How do the different kinds of straw compare as to heating value?

CLARKE SCHOOL OF TRACTION ENGINEERING.

28. How many foot pounds of work are done in raising 125 pounds to a height of 17 feet?

29. A horse exerts a pulling force of 220 pounds on the traces and travels at a rate of 3 miles per hour; how many horse power of work is he doing?

30. A ton of hay is lifted from a wagon into the loft of a barn, a vertical distance of seven feet; how many foot pounds of work are expended?

31. The average pressure on the piston of an engine is 4,460 pounds throughout the stroke and it travels 480 feet per minute; how many horse power is it developing?

32. How much work does it require to pump 280 gallons of water per minute from a well 90 feet deep; what horse power?

33. A man weighing 200 pounds climbs a stairs 12 feet high, how much work does he do?

34. A boiler evaporates 4,000 pounds of water into steam at atmospheric pressure, or its equivalent, from feed water at 212 degrees F. in ten hours; what is its horse power?

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PART VI

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Clarke School of Traction Engineering

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LESSON WITH QUESTIONS

TRACTION ENGINE GEARING

PART VI

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

LESSON VI.
TRACTION ENGINE GEARING.
MOUNTING THE BOILER.

TYPES OF MOUNTING.

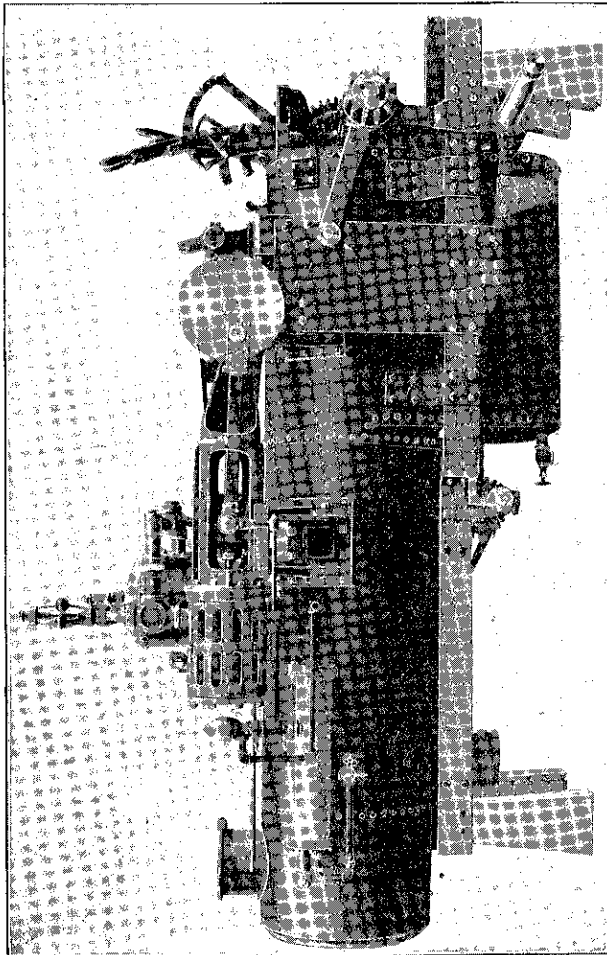
- 1 There are two principal methods of mounting a traction engine, one in which the boiler is made the framework for the whole machine and the other in which an independent framework is built up which is used as the foundation for the engine and to which the wheels are attached; the boiler being hung independently in this framework.
- 2 There is also another style of mounting which may be termed the "mixed style," in which an attempt is made to relieve the boiler of the stresses due to traction, by attaching a framework to it which carries the main wheels and countershaft. Each of these types or classes will be discussed under a separate heading.
- 3 *Boiler as Framework.*—By far the larger number of traction engines are built in this style, and up to within very recent years it was the only style in use. In this form of construction the engine is attached directly to the boiler by means of separate brackets bolted to the firebox or by means of axles fastened to the boiler with brackets. Power is transmitted from the engine to the drivers by means of gears whose axles are bolted directly to the boiler, or else supported on a shaft attached to the boiler with brackets. The front end of the boiler rests upon a

bracket which is attached to the front wheels by means of a knuckle joint.

- 4 As indicated above, there are several methods of attaching the gears and the drive wheels to the boiler, and considerable controversy has arisen as to which is the best. No attempt will be made herein to prove the relative merits of the different styles of construction, but a number of the prominent makes which illustrate the different types will be illustrated and described, thus placing the reader in a position to form his own conclusions.
- 5 The advantage gained in using this type of construction is that it is possible to build a much more compact machine and one that looks considerably neater, and at the same time reduce the weight of metal used in construction to the lowest possible amount. The matter of weight is quite an important one from two points of view. The lighter the engine the cheaper it is to build and the less power there will be required for self propulsion.
- 6 The principal disadvantage lies in the fact that all the strains of traction must pass thru the boiler, thus making it do double duty; first, as a steam generator and, second, as the framework for a heavy machine which is subjected to very severe racking and twisting stresses; the result of which is apt to cause considerable working at the joints and around the staybolts.
- 7 *Independent Framework.*—Within the past five or six years several manufacturers have brought out traction engines in which a separate framework is provided to carry

the engine, gears, ground wheels and boiler. In this style of construction the boiler is relieved of all the strains of traction and is only required to furnish steam for the engine.

- 8 Where a separate framework is used it is necessary to mount the engine above the boiler, or else follow the locomotive style of construction in which the boiler is elevated above the framework and the engine is placed underneath. The advantages of this type of engine are on the side of greater strength and safety for the boiler, and the disadvantages arise mainly on account of extra weight, and the difficulty of arranging all the machinery to good advantage.
- 9 *Mixed Style of Mounting.*—Another style of mounting shown in Fig. 100 illustrates what may be termed the "mixed style" of mounting in which a framework is provided for the wheels and countershafts, thus relieving the firebox by distributing the stresses over a large area and also relieving it of the heavy stresses between countershaft and drivers. However, since the engine and driving mechanism are attached to the boiler, all the strains of traction must necessarily pass thru it.
- 10 *Spring Mounting.*—There seems to be considerable difference in opinion as to the merits of spring mounting. A number of the leading manufacturers of traction engines provide a spring connection between drive wheels and boiler and almost an equal number dispense with them almost entirely.
- 11 The object of the springs is to provide an elastic form of construction which will take up the wear and shock of



Boiler Supported by Frame Work, Fig. 100.

rough roads without injury to the boiler or any of its connections. With this idea in view the believers in spring mounting have placed springs between the drive wheels and boiler, springs between the front axle and boiler, and springs in the steering chains. The boiler then rests upon springs all around and motion is transmitted from the drive shaft to the drive wheels thru a spring gear.

- 12 In such a style of construction any sudden shock due to rough roads will come gradually upon the wearing parts and there is little danger of breakage. Likewise, the cushion gear takes up the shock occasioned by the drive wheels striking an obstruction in the road and possibly prevents the gears from breaking, in some cases; while the springs in the steering chains often prevent them from breaking when the front wheels strike a stone or other obstacle in the road.
- 13 The introduction of springs, while in itself a very good thing, brings with it several undesirable features, the most important of which is the difficulty of maintaining the exact distance between the centers of the shafts at all times. If the distance between the shafts vary, the gears do not mesh properly and, hence, they wear unevenly and soon cut out.
- 14 Some manufacturers who build spring mounted engines for general threshing advocate the taking out of these springs and the substitution of a solid block when the engine is used for plowing or heavy freighting on account of the wear occasioned upon the gears when the springs are used.
- 15 Those companies that do not use the spring mounting

depend upon rigid gears. Nearly all, however, place spiral springs in the steering chains.

- 16 The advantages of spring mounting are found in the relief from sudden blows which this form of construction provides. Its disadvantages are found in the varying distances between shaft centers, which may cause the gears to mesh badly, in the greater number of sliding parts which, when they wear, throw the gears out of line, and trouble and delay from broken springs.

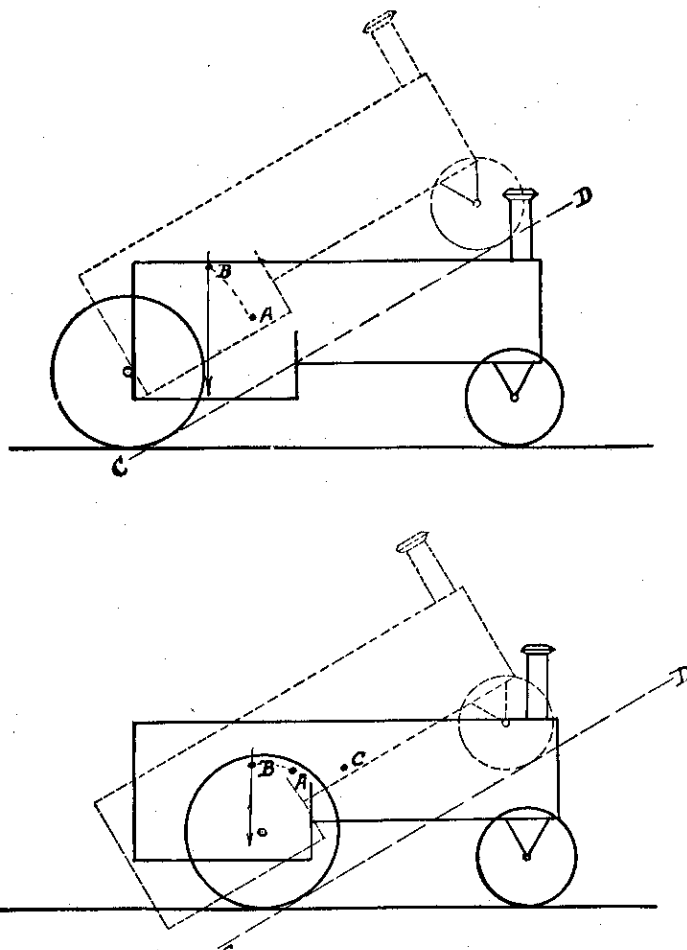
- 17 *Influence of Weight on Traction.*—The load which a traction engine is capable of hauling depends upon the power of the engine and the weight on the drive wheels. In general, the greater the amount of weight upon the drivers, the greater will be the tractive effort of the engine; in fact, one of the reasons for making locomotives so heavy is to get weight enough upon the drivers to keep the wheels from slipping on the rails in pulling heavy loads. If all the weight of the engine could be placed upon the drivers the engine could exert the greatest possible pulling power consistent with its strength. Such an arrangement, however, would be impractical for various reasons. In the first place, there must be sufficient weight upon the front wheels to hold them firmly to the ground in order to make the engine steer properly. In the second place, there must be enough weight ahead of the rear axle to prevent the engine from tipping backwards in going up an incline. Consequently, the center of gravity or the center of weight of the engine, in order that it may be able to pull the maximum load and at the same time be free from any tendency

to rear, should be a little ahead of the rear axles. At the present time with the long boilers in general use there is practically no difficulty with "rearing," but a few years ago when the boilers were made much shorter, considerable difficulty was experienced in this way, and many devices, such as placing the engine well forward, mounting the water tank on the front end, etc., were resorted to, to overcome this trouble.

- 18 The effect of the distribution of weight is clearly shown in Fig. 101.

EFFECT OF DISTRIBUTION OF WEIGHT IN TRACTION ENGINES.

- 19 In the upper diagram the centre of weight is assumed to be at A, or, in other words, we will assume that the weight is so distributed in the engine that it would balance on a pivot at A. Now when the engine starts up an incline such as C D, the whole machine tips upward and the point A moves to B. The same thing is also true in the lower figure with this difference, that in the first figure a vertical line drawn through B falls ahead of the rear axle, and in the second case, behind; consequently the first engine will have no tendency to rear while the second one is sure to, because the centre of weight or centre of gravity falls outside of the supports. It must not be understood by the reader that all engines, or, in fact any of them at



Effect of Distribution of Weight in Going Up an Incline. Fig. 101.

the present time, with the wheels mounted on the firebox sides will rear, because the centre of weight will be found, not at A, but at some point C, much farther ahead of the rear supports than A. However, if the weight were centred at A, the engine would certainly upset in going up a steep grade.

- 20 The result of such an arrangement as shown in the figures is that the lower engine will have more pulling power for its weight and strength on a level than the upper one, but not so much in going up a hill.
- 21 *Rear Mounting.*—In this type of mounting the rear axle, carrying the drive wheels, is attached to the rear of the fire box by means of suitable brackets. The countershaft appears immediately above the main axle and is attached to the boiler with suitable connections. This style of construction is carried out in different ways by different manufacturers, some using springs, others dispensing with them.
- 22 *Rear Mounting with Springs.*—A well known example of spring mounting in this style is shown in Figs. 102, 103, and 104.
- 23 Where the counter shaft is placed directly above the axle it is evident that if spring mounting is to be employed, some provision must be made to maintain the countershaft and axle at a fixed distance from each other, otherwise the gears will not mesh correctly. To accomplish this, and at the same time retain the springs, so called radius links are used, which hold both the axle and the counter shaft to the fire box sides, and a distance bar on each side to maintain a uniform distance between the countershaft and axle.

- 24 The boiler is supported from the axle by means of heavy brackets bolted to the rear of the firebox, resting on heavy compression springs which in turn are supported by strong rods attached to the axle.
- 25 The counter shaft is attached to the sides of the fire box

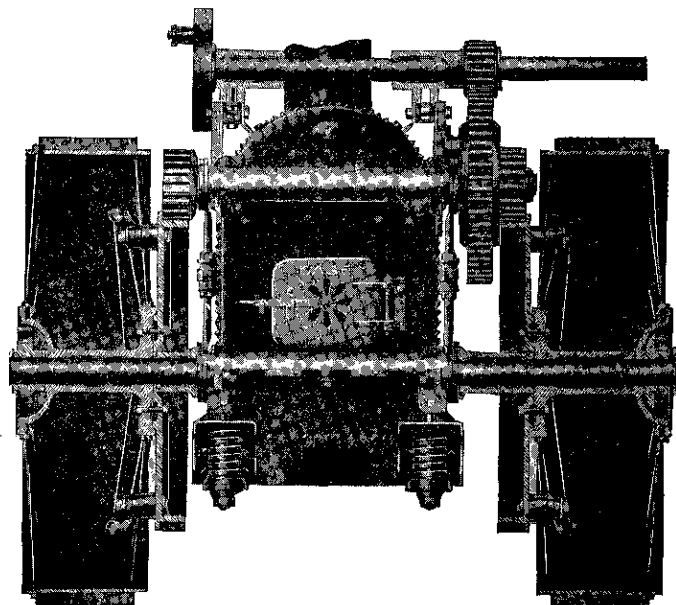


Fig. 102.

by means of the upper radius bars and prevented from moving endwise by means of another link shown in Fig. 104.

- 26 The boiler is thus free to move up or down as far as the

springs will permit without disturbing the relative distances between counter shaft and axle.

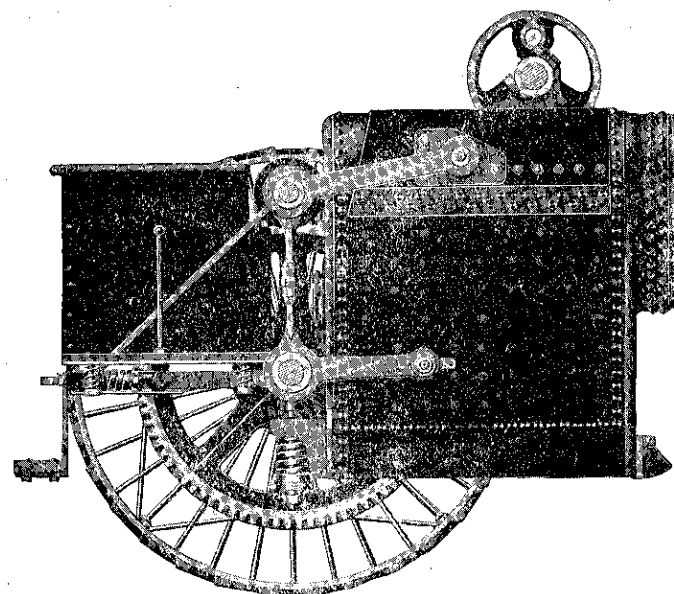


Fig. 103.
Rad. Link to Prevent Countershaft from Moving Endwise.

- 27 *Another Method of Rear Mounting with Springs.*—One style of a certain Mfg. Co.'s regular traction engines is rear mounted and provided with springs in such a way that the main axle may tilt up or down at either end. The mechanism by which this is accomplished is shown in Fig. 105 and described below. Motion is transmitted from

the driving pinion A, to the large gear B, which rotates on a large hollow spindle M. The axle passes through M, and can move up or down a considerable distance without touching it.

- 28 A malleable iron ring D, is attached to B, by means of four rods C, placed opposite each other. Two of these rods

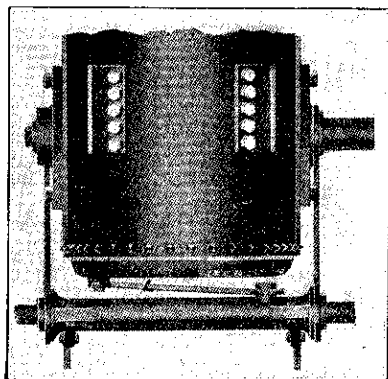
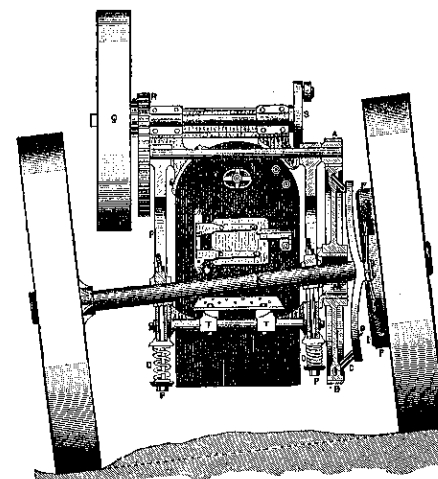


Fig. 104.

are in tension during the forward motion, the other two when moving backward. Four other rods E, at the right angles to each other are attached to D and to the differential gear F. A universal coupling, permitting motion in any direction, is provided, where these rods are attached to D. The holes in the lugs on F, through which these rods pass, are large and permit some side motion of the rods, while the spiral springs at the ends form a spring connection between

D and the differential gear, which relieves the latter of sudden shocks. By means of ring D and the system of levers above described, motion can be transmitted to the differential gear even if the axle is tilted one way or another without causing any of the gears to be out of mesh.



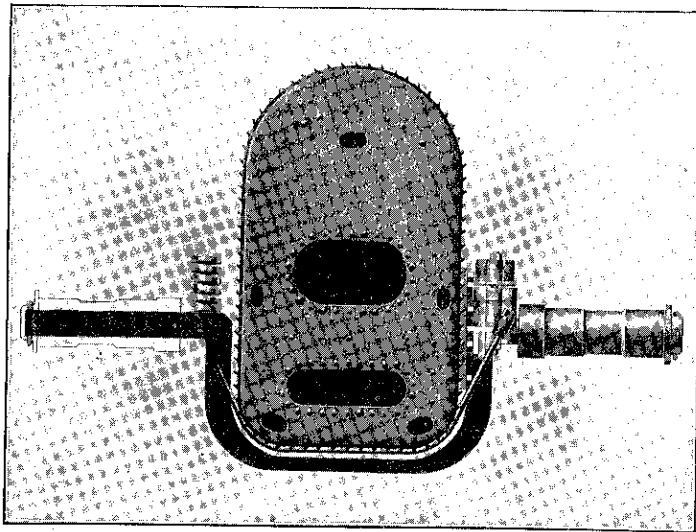
Spring Mounting in Which the Rear Axle is not Held Parallel to the Counter Shaft. Fig. 105.

- 29 A heavy bracket, bolted to the side of the boiler, rests on springs O which are supported from the axle by means of bolts P.
- 30 *Rear Mounting Without Springs.*—When this style is adopted both the main axle and the counter shaft are bolted

rigidly to the rear of the fire box and the distance between centres is thus made unvarying.

31 The adoption of this style of construction makes it convenient to bolt the brackets to the corners of the fire box where that structure is strongest and least liable to spring out of shape.

32 *Through Axles Under Fire Box.*—Several of the leading companies are building engines in which a heavy bent axle



Through Axle Under Fire Box, with Springs. Fig. 106.

extends under the fire box, thus obtaining some of the advantages of a through axle and at the same time setting the

drivers well forward where they will carry the greatest amount of weight.

33 An example of this style of mounting is found in Fig. 106.

34 A heavy bracket on each side of the fire box is fitted with guides in which a sliding piece, fastened to the axle, works up and down against a heavy coiled spring which supports the boiler.

35 The boiler itself is also supported by a truss rod extending from one side of the bent axle to the other.

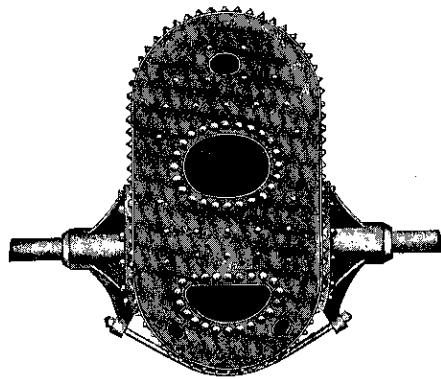
36 Where this style of construction is used the counter shaft must be carried in front of the fire box and in under the main shell.

37 *Stub Axle Mounting* is a term applied to those boilers having a bracket, provided with an axle, bolted to the side of the fire box. Some builders provide springs between the boiler and axle, while others depend upon a solid axle and bracket. In the largest sized engines these brackets cover the greater part of the fire box walls and are made very heavy.

38 In this style of construction the alignment of the axles depends entirely upon the stiffness of the fire box walls. If they should spring, the wheels would be thrown slightly out of line and the gears would mesh badly. This tendency to spring is obviously greater with small brackets than with large ones, consequently heavy plowing engines built in this way must be provided with brackets covering a large part of the fire box sides. The fact that engines so built have stood the test under the most severe conditions is proof that

when properly designed and constructed this style of mounting is satisfactory.

- 39 The advantages gained by the stub axle style of mounting, are, neatness of appearance, easy distribution of the weight, and convenient arrangement of the working parts. The disadvantages may be summed up about as follows: 1st, the liability of error in getting both axles in perfect alignment. 2nd, the tendency for the boiler walls to spring sufficiently to throw both the wheels and gearing out of

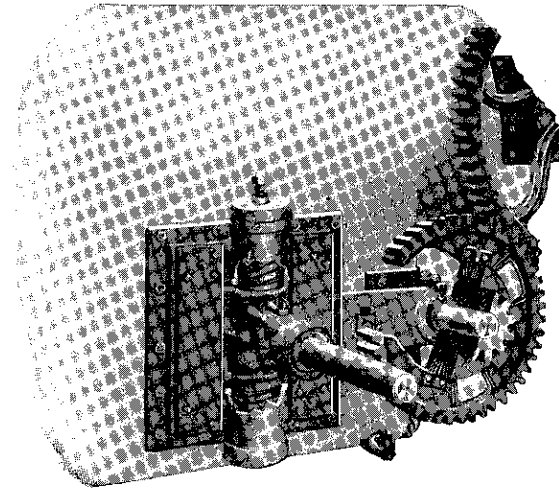


Stub Axle Mounting Without Springs. Fig. 107.

line. 3rd, the strains on the fire box walls which may, if the strength of all parts is not well considered, cause the joints to leak.

- 40 *Stub Axle Mounting Without Springs.*—An example of this type of mounting is to be found in Fig 107. A reference to the drawing will show heavy brackets bolted to

each side of the fire box having two lugs on the lower side through which truss rods pass underneath the boiler. These truss rods serve to support the boiler and also to relieve the load on the lower stud bolts which secure the

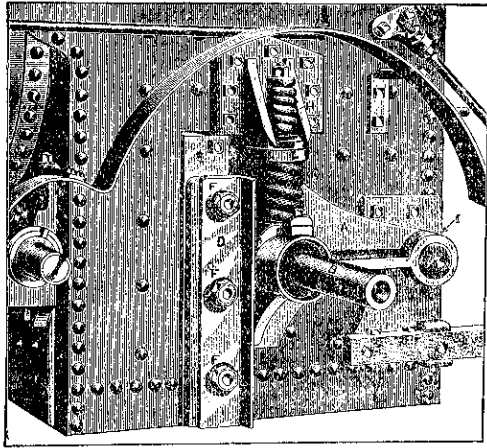


Stub Axle Mounting with Springs. Fig. 108.

brackets. The manufacturers submit the claim that there is sufficient spring in the fire box walls to relieve sudden shocks without inserting springs.

- 41 *Stub Axle Mounting With Springs.*—Fig. 108 is a good example of this style of construction.
42 Reference to the figure will show that the casting carrying the axle is swivelled on the countershaft by means of

a bracket arm which rests between two heavy spiral springs secured in the main bracket. This axle bracket moves up and down between guides which are bolted to the bracket and the side of the boiler. The object of the swivelled arm is to hold the axle at a fixed distance from the countershaft,



Spring Mounting. Stub Axle Construction. Fig. 109.

thus causing the gears to mesh properly at all times irrespective of the position of the boiler.

- 43 Where some means are not provided to maintain this distance some manufacturers advise, in heavy road work, such as plowing or grading, to take out the springs and put in blocks, otherwise the gearing may wear considerably on account of the varying distance between centres. Of

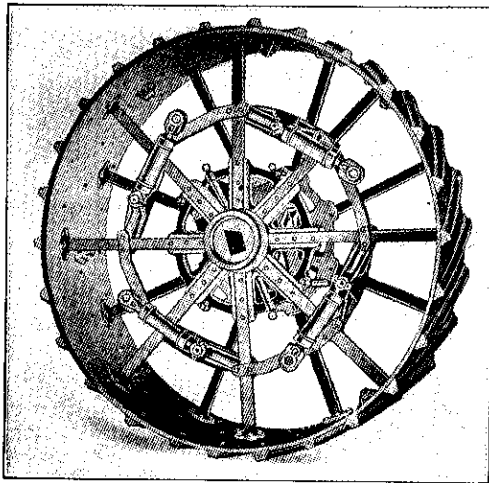
course, since the center line passing through the centers of the countershaft and axle is practically horizontal, variation in distance between the two shafts, due to any up or down movement of the axle, will be very slight in ordinary work, and where the strain on the gearing is not very heavy it will not injuriously affect them to any great extent. It is only in very heavy work that this variation makes any considerable difference.

- 44 *A Characteristic Type of Mounting.*—Fig. 109 shows a style of mounting in quite general use. The axle B is rigidly attached to a casting A which is pivoted at I, to a bracket fastened firmly to the firebox. The other end of bracket A slides between the guide plates E and D. Bolts F pass through slotted holes in A and are provided with nuts to adjust the distance between the guide plates so that A can move up or down without any side motion.
- 45 The weight of the boiler is carried on the bracket L which rests between two springs H and G. Any downward movement of the boiler is arrested by the springs G and any upward movement by H.
- 46 Spring H is independent of G and is held in place by a bolt passing through casting L and attached below. The master gear in this construction moves in the arc of a circle convex to the driving pinion.
- 47 *Mounting the Return Flue Boiler.*—In this type of boiler the rear axle passes underneath the rear end of the boiler and is attached thereto by means of a saddle bracket. This makes a strong style of mounting in which the boiler is not subjected to as severe strains as in the case of firebox

boilers, since both the engine and driving gears are bolted to it.

48 *Spring Mounting of Return Flue Boilers.*—A method of accomplishing this is illustrated in Figs. 110 and 111. The main axle shaft is made rectangular and passes through a rectangular opening in a case hardened trunion which revolves in the hub of the drive wheel.

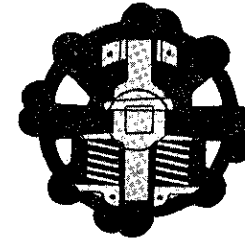
49 Spiral springs are inserted in this trunion in the rec-



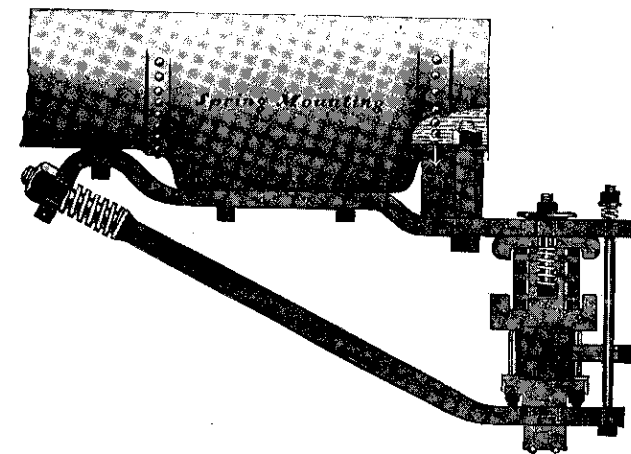
A Spring Drive Wheel. Fig. 110.

tangular slot underneath the square axle and form a spring support for the boiler. The wheel revolves on this trunion. Fig. 112 shows the spring mounting at the front end of the boiler.

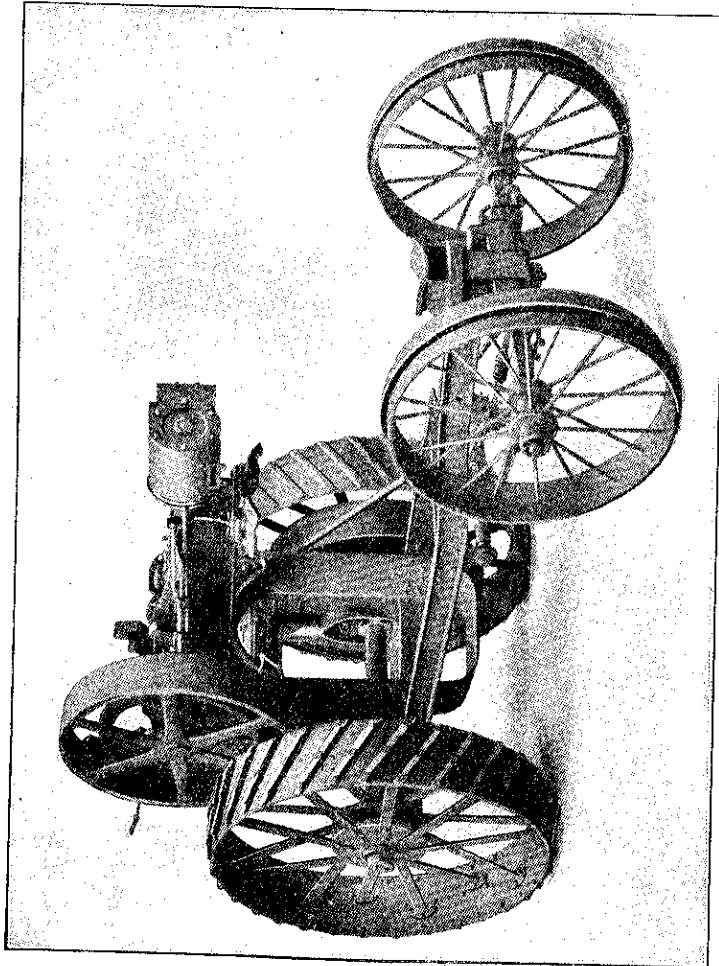
50 *Boilers With Independent Frame.*—Engines built with an independent framework are constructed in two ways. One scheme is to mount the engine above the boiler, the other is to put the engine and all working parts under-



Hub of Spring Wheel. Fig. 111.



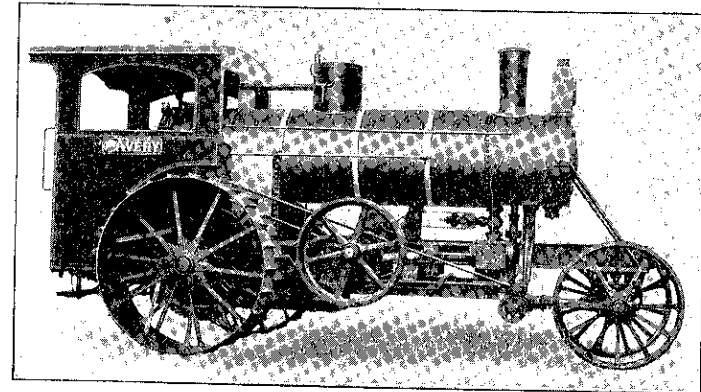
Front Mounting of One Style of Return Flue Boiler. Fig. 112.



Independent Frame Work. Fig. 113.

TRACTION ENGINE GEARING.

- neath, thus following the plan adopted in all locomotives.
- 51 Fig. 113 illustrates a style of engine which follows the first plan. In this engine a pair of channel beams reach from the front axle to the rear axle and forms the foundation for the framework. Two heavy plates at the rear of the machine riveted to these channels extend upward and support the engine, countershaft and main axle bearing, while a wide stirrup supports the firebox. A chair resting on the front axle supports the front end of the boiler. This

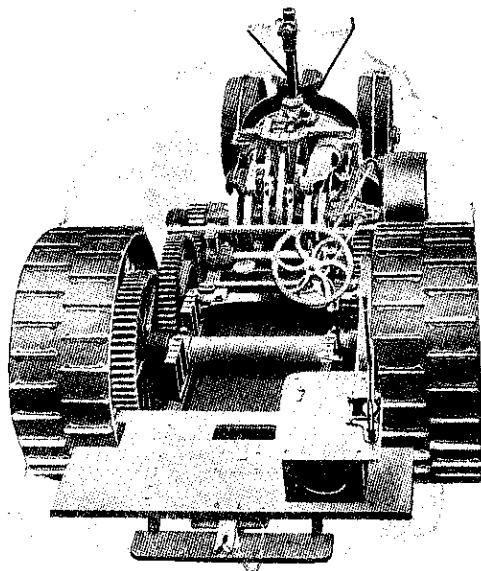


Another Style of Independent Frame Work. Fig. 114.

- arrangement of mounting forms a truck for carrying the boiler without subjecting it to any of the strains of traction.
- 52 The engine and main shaft are placed well toward the rear in this arrangement, thus making a straight drive be-

tween the driving pinion and differential gear and dispensing with the intermediate gear.

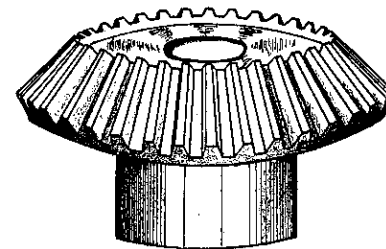
- 53 The other style is well illustrated in Figs. 114 and 115. The framework consists of heavy channel beams which support the engine, gearing and drive wheels. The boiler is mounted on the framework and is thus independent from the engine and all working parts.



Another View of Fig. 114—Fig. 115.

- 54 *Gearing.*—The term gearing is used to designate those parts of a machine by which motion is transmitted from one part to another.

- 55 It may consist of toothed wheels, friction wheels, chains, screws, or any combination of these devices. The term gear is applied generally to a toothed wheel, while the term *train of gears* applies to a number of toothed wheels in mesh with each other which transmit motion from one shaft to another, as for example the train between the main shaft and drive wheels.
- 56 There are a number of different kinds of gears, the commonest of which are spur gears, annular gears, bevel gears and worm gears; all of which are found on traction engines.



A Bevel Gear. Fig. 116.

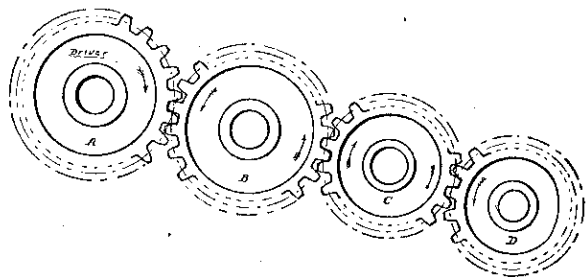
At A, Fig. 123, there is an illustration of a spur gear. It consists of a cylinder having parallel teeth cut on its surface. A bevel gear is shown in Fig. 116, in which teeth are cut on the surface of a portion of a cone. Bevel gears are used where motion is transmitted between two shafts which make an angle with each other.

- 57 An annular gear is just like a spur gear except that the teeth are cut on the inner surface of a cylinder instead of

on the outer surface. Some manufacturers use an annular gear for the main driving gear.

58 Where two gears are in mesh, one large, the other small, the large one is called the gear, the small one the pinion. This applies to either spur gears or bevel gears.

59 A *worm gear* is used where it is desired to effect a great reduction in speed between the driver and follower, and where the shafts are at right angles with each other. A familiar example of worm gearing is seen in the steering gear. Here the object is not so much a reduction of speed as it is to obtain a considerable twisting effort on the chain



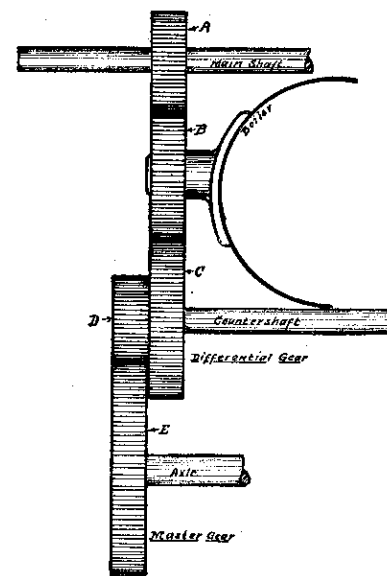
A Simple Train of Gears. Fig. 117.

drum and the necessity for a gear that will not have a tendency to run backwards.

60 A simple train is made the subject of illustration in Fig. 117. The speed of the last gear D is just the same as though gears B and C were not used and D meshed directly with A. The only effect of the intermediate gears is to change the direction of rotation of the follower if an odd

number of gears are put in such as one or three or five; but when an even number of gears, as two, four or six are inserted there is no change either in speed or direction of the last gear of the train.

61 Fig. 118 represents a compound train of gears. The ob-



A Compound Train of Gears. Fig. 118.

ject of using a compound train is to either increase or decrease the speed of the last gear and possibly to change its direction of rotation.

62 In the accompanying figure if A is the driver and E is

the last gear of the train, the speed of B will be greatly decreased. But if B be the driver, and A the last follower, then the effect is to multiply the speed, as will be explained under the "rules for figuring the speed of gears."

63 *Materials Used in Gears.*—The gears used on traction engines are made of cast iron, cast steel and semi-steel. It has only been since steam plowing and heavy roadwork has come into vogue that anything but cast iron has been used. Owing to the grit and dirt which get in between the teeth, the gears have a tendency to wear out pretty rapidly, especially where they are used continuously in plowing or freighting. Furthermore, they have to be made very strong in order to withstand the heavy work they are called upon to do.

64 The common width of drive gears for traction engines a few years ago was $3\frac{1}{2}$ inches for 25 horse engines. At the present time they are made from 5 to 7 inches wide. When gears are made of cast iron as wide as this they are very heavy and so efforts have been made to use other material having greater strength which would make it possible to reduce the weight to a considerable extent without weakening the gear.

65 Partial success has been attained by the use of steel and semi-steel castings. Steel castings are made by either the open hearth or the Bessemer process and are cast in molds like ordinary cast iron. Semi-steel, so-called, is simply a mixture of cast iron and steel, consisting mostly of iron and a small portion of steel scrap, which is either put into the cupola and melted with the iron, or else thrown into the

ladle in the form of chips or shavings. None of these materials have been wholly satisfactory.

66 Cast iron is heavy and brittle but it wears exceedingly well. The friction of the teeth rubbing upon each other does not cut away the metal nearly so fast as in the case of steel gears. Steel, on the other hand, is light and tough. A steel gear tooth will bend before it will break but it does not wear well, consequently the teeth become thin in a comparatively short time and consequently weak.

67 Semi-steel is apt to be uncertain in composition, some parts of it being exceedingly hard and other parts quite soft, thus showing that it is difficult to secure an intimate mixture of the iron and the steel. On account of the difference in hardness between different parts of even the same tooth, wear does not take place evenly across them. As yet there is no material known that is entirely satisfactory for cast gearing doing rough work. While each of the kinds mentioned above have desirable qualities peculiar to themselves it seems impossible to unite all of these advantages of lightness of weight, strength and wearing qualities in one and the same product.

68 Gears made from metal patterns are perhaps somewhat better than those made from wood, because the teeth in the metal pattern are more perfectly formed; the gear is more nearly true, and the teeth are more nearly straight than when wood patterns are used.

69 *The Speed of Gears.*—The speed at which a gear runs depends upon its number of teeth and the number of teeth in the driver. If the follower gear has the same number

of teeth as the driver it will run at the same speed as the driver. If it has half as many teeth as the driver, it will make twice the number of revolutions, and in every case will revolve in the opposite direction to the driver.

- 70 When three gears are in mesh in straight line the size of the middle gear makes no difference with the speed of the last driven gear, but the direction of rotation of the latter is reversed. To show that the middle gear has no effect upon the speed of the last driven gear it is only necessary to consider that when a tooth of the driver passes a given point it pushes one tooth of the middle gear an equal distance. This in turn, pushes a tooth of the third gear the same distance, consequently the third gear moves a distance exactly equal to what it would travel if perfectly in mesh with the driver.

- 71 *To Find the Speed of the Last Gear of a Train.—Use the number of teeth in the driver for the numerator of a fraction, the number of teeth in the last driven wheel for the denominator, and multiply by the speed of the driver. The result will be the speed of the driven wheel neglecting all intermediate gears.*

- 72 *For example.—*Suppose there are three gears A, B and C in mesh forming a simple train. A has 20 teeth, B, 60 teeth and C, 40 teeth. A makes 50 revolutions per minute; how many revolutions does C make?

- 73 *Solution.* $\frac{20}{40} \times 50 = 25$ the number of revolutions which C will make in one minute.

- 74 In a simple gear train it does not make any difference

how many gears are in mesh, all that need be considered is the number of teeth in both the first gear and the last gear and the speed of the driver.

- 75 *Example.—*Five gears, A, B, C, D and E are in mesh. A has 60 teeth; B, 50; C, 80; D, 30; and E, 100. A is the driver and makes 80 revolutions per minute; how many does E make?

- 76 *Solution.* $\frac{60}{100} \times 80 = 48$.

- 77 *Rule for Figuring Speed in a Compound Gear Train.—Use the number of teeth in each driver as the numerator, and the number of teeth in each corresponding follower as the denominator of a fraction. Multiply these fractions together and the product by the speed of the first driver; the result will be the speed of the last follower.*

- 78 *Example.—*Referring again to Fig. 118. A is the first driver and D the second. B, C and E are the respective followers. A has 18 teeth; B, 56; C, 70; D, 16 and E, 72. Suppose A makes 200 revolutions per minute; how many does E make?

- 79 *Solution.* $\frac{18}{70} \times \frac{16}{72} \times 200 = 11 \frac{3}{7}$ Ans.

- 80 The rules for figuring the speed in a compound train of gears are almost the same as for a simple train, only care must be taken to consider which is the *driver* and which the *follower* in each case.

- 81 Where either a considerable reduction or multiplication of speed is desired, and where a reversible motion is essential, the result can be accomplished by the use of a com-

pound train of gears. Where only a simple reduction of motion is desired, it can be obtained with the use of a worm gear, but, as stated before, the worm wheel can rarely be used as the driver.

82 *Worm Gearing.*—In figuring the reduction of speed by using worm gearing it is usual to consider that the worm is a gear of only one tooth. Then, if the worm gear has 60 teeth, it will require 60 turns of the worm to make the gear revolve once. By making the gear as large as we please it is perfectly possible to effect any reduction of speed desired. As worm gearing is usually built, it is self-locking; that is, the worm wheel can not be made to drive the worm. An exception to this rule, however, is found in certain types of machines, as for example, cream separators. Here a very great multiplication of speed is desired which is accomplished by making the worm wheel the driver.

83 All the parts must, however, be made very nicely and the construction of the worm must be changed somewhat.

84 *Pitch of Gears.* The term "*pitch of a gear*" designates the size of the teeth, the smaller the pitch, in involute gearing, the larger the teeth. In involute gearing diametral pitch is used; i. e., in a 5 pitch gear there are 5 teeth in the circumference for each inch of diameter. A 5 pitch gear 4 inches in diameter, therefore, contains 20 teeth. The depth of the teeth is equal to a little more than twice the reciprocal of the pitch. For example, in a 5 pitch gear the total depth of tooth equals 2 times $1/5$ plus a small amount necessary for clearance.

85 In the involute system of gearing 12 teeth are considered the smallest number which may be used in a pinion. The reason for this is that the roots of the teeth become too thin if a fewer number of teeth are used. It follows, therefore, that the teeth of pinions having a small number of teeth are weaker than those of gears; the smaller the pinion, the weaker the teeth. This is one of the reasons why the pinions on the countershaft which drive the main wheel are more apt to break than the gears. Furthermore, since they have only a small number of teeth and each tooth receives more wear than in the gear, they consequently wear out much sooner. Many manufacturers at the present time are changing the size of their gearing in such a way as to avoid using very small pinions. The result of such efforts can not fail to increase the strength of the gearing and make it wear much longer.

86 The reason that involute gears are preferred for traction engine work is because a slight variation in the distance between the centres of the shafts makes no particular difference to the correct working of the gears. This is not true of gears made on any other system.

87 *Systems of Gearing.*—There are two systems of gearing in common use; viz., the cycloidal and the involute, and traction engine gearing is made in both systems. The involute system, however, is used more extensively for reasons above stated.

88 If a string be wound about a circular post and then unwound, holding it taut at the same time, the end of the

cord will describe a curve known as the involute, and it is this curve which forms the faces of gear teeth constructed on the involute principle.

- 89 *Traction Engine Driving Gear Train.*—On a well known make of traction engine, the driving pinion A has 18 teeth; the intermediate gear B, 54 teeth; the differential gear C, 72 teeth; the master pinion D, 12 teeth; and the master gear or driving gear 70 teeth. The main shaft makes 260 revolutions per minute; how many does the drive wheel make?

Solution. $\frac{18}{72} \times \frac{12}{70} \times 260 = 11\frac{1}{7}$. Ans.

- 90 The intermediate gear forms with the gears A and C a simple train and so does not need to be taken into consideration at all, since it neither increases nor decreases the speed of B.

- 91 The diameter of the road wheel is six feet. If it makes $11\frac{1}{7}$ revolutions per minute; how fast does the engine travel on the road?

- 92 *Solution.*—The circumference of the road wheel is $6 \times 3.1416 = 18.8496$ feet. Therefore, every time it turns around, the engine moves a distance of 18.8496 feet, or, an amount just equal to the circumference of the wheel.

- 93 In one minute, therefore, it will move $11\frac{1}{7} \times 18.8496$ or 210.04 feet.

In one hour the engine will travel 210.04×60 or 12602.4 feet.

- 94 There are 5280 feet in one mile, therefore the engine

will travel as many miles per hour as 5280 is contained in 12602.4 or 2.38 miles per hour.

- 95 *Road Speed of Traction Engines.*—The speed of a traction engine on the road depends, as shown above, upon the number of teeth in the gears in the driving train, and upon the speed of the main shaft. These gears are so proportioned in most cases that when the engine is running at its normal speed it will drive the whole machine along the road at a rate of from $2\frac{1}{4}$ to $2\frac{3}{4}$ miles per hour. For ordinary work, in moving from one place to another in threshing, the above speed is sufficient. A road speed much greater than $2\frac{1}{2}$ miles an hour is too much in hauling one of the large sized separators over rough country roads, because of the racking and twisting which it receives in passing over obstructions in the road. There is not the least doubt but that separators have been damaged far more by hustling on the road than when threshing. Moving one of the large 44 by 72 separators is almost like moving a house, and a heavy shock occasioned by the wheels falling into a rut or passing over a stone, is sure to twist the framework and cause the joints to work loose.

- 96 Likewise in plowing, a speed of 2 to $2\frac{1}{2}$ miles per hour seems to be sufficient because a much faster rate throws the furrows badly. It is also a fact that the slower road speed an engine has, with the same speed of main shaft, the heavier load it can draw, even with the same size of engine cylinder and the same steam pressure.

- 97 When an engine is used for freighting purposes only, it is often desirable, in coming back empty, to have an ar-

rangement whereby the speed may be changed, thus permitting the engine to move slowly when loaded and fast on the return trip when there is no load. To accomplish this purpose a double speed gear is provided.

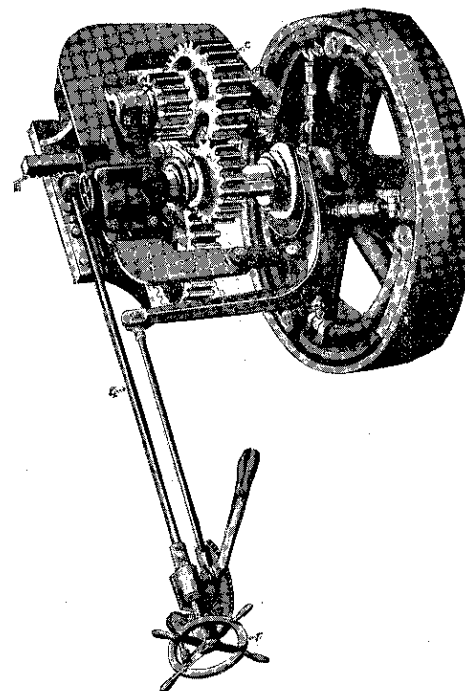
98 *Double Speed Gears.*—Fig. 119 is an illustration of one style of double speed gear. The main spur pinion A is considerably larger than that used on most engines, consequently, when it is directly in mesh with the intermediate gear B, the engine moves on the road at a high rate of speed; but when it is shifted over along the main shaft until it meshes with C, the speed is reduced. First between A and C, then between D and B, because C is larger than A and B is larger than D. Gear A is shifted along the shaft by means of a pinion on the end of rod G, which meshes with a rack E. This is actuated by means of a hand wheel F, which is located within easy reach of the engineer at the rear of the engine.

99 *The Intermediate Gear.*—When an intermediate gear is used on a plowing or freighting engine it is mounted on a very heavy stub axle bolted to the side of the boiler. The object being to give it sufficient bearing surface so that it will not wear sufficiently in the life of the engine to cause any difficulty through lost motion and bad alignment. Many builders are dispensing with an intermediate gear altogether in their heavy engines, by gearing directly from the main shaft to the differential gear. The advantage claimed for this change, and it seems a reasonable contention, is that they thus overcome the difficulties incident to

TRACTION ENGINE GEARING.

the springing of the engine and the throwing of the intermediate gear partly out of line.

100 *The Differential Gear,* or compensating gear, as it is fre-



One Style of Double Speed Gear. Fig. 119.

quently called, is necessary on all traction engines, automobiles, or other road engines, in order to enable it to turn corners. Whenever a wagon or other vehicle turns

a corner, the outer wheel must travel a greater distance than the inner one because it moves on the arc of a larger circle. Consequently, if both wheels revolved at the same rate of speed, the inner one would be obliged to slip. On a heavy machine with wheels provided with grouters, this would throw a heavy load on the engine and strains on the wheels and driving gears causing considerable wear and possible breakage, at the same time making an engine that would not turn readily and with certainty. In order to overcome these objections a differential gear is placed on the countershaft which enables one wheel to adjust itself to the speed of the other under all conditions. The mechanism of this device is clearly illustrated and described in Fig. 120. The differential gear consists of the spur gear K, bevel gears, D and E, and bevel pinions F. The bevel gear E, and driving pinions B, are cast in one piece. Gear K runs loose on the countershaft and contains bearings in which the axles of pinions F revolve.

101 Bevel gear D, and spur gear C, are keyed to the countershaft while E runs loose. Motion is transmitted to the countershaft through the large gear K. When both road wheels G and H meet the same resistance the pinions F, lock D and E together and the whole gear revolves as a solid gear transmitting equal motion to both master gears. If gear G, however, were lifted from the ground, thus being free to turn, it would meet no resistance; while H, being on the ground, would meet with considerable resistance.

102 In this case any motion given to K would cause pinions F to revolve and thus drive gear D at double its usual rate

of speed, but, since the wheel to which G is secured is free to turn, no motion will be given to the engine.

103 If on the other hand gear H were free to turn without

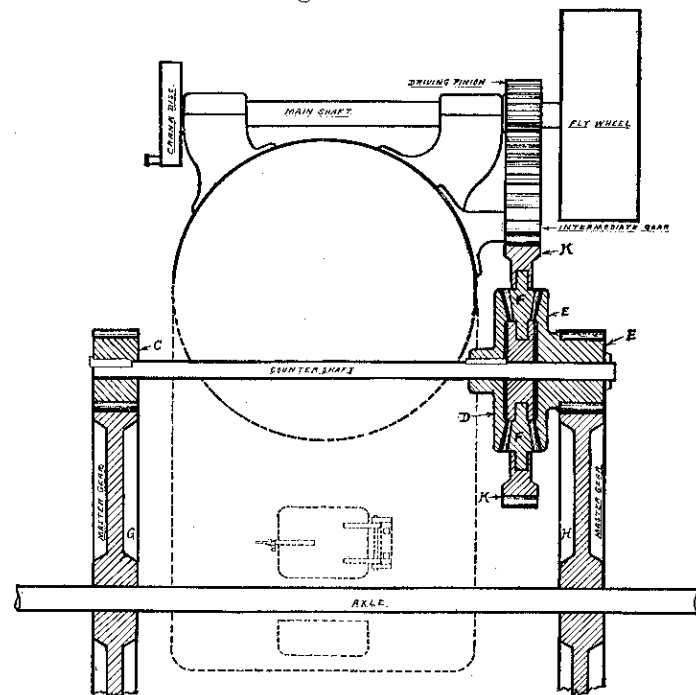


Diagram of Differential Gear. Fig. 120.

resistance, and the wheel to which G is secured were on the ground any motion given to K would again cause pinions F to revolve and B would be driven at double its usual rate,

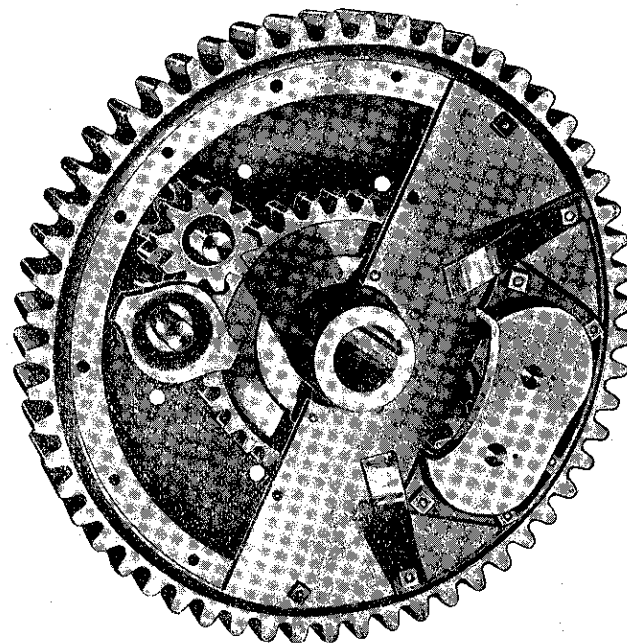
but being loose on the countershaft it can not transmit any motion to the opposite drive wheel. The result, in this case, is that it would spin around at double its usual rate of speed and the engine would stand still as before. If, however, the right road wheel should meet with slightly less resistance than the left, as would be the case in turning to the left, the pinions *F* would thus enable it to travel enough faster to compensate for the turn.

104 *One Drive Wheel in the Mud.*—It is evident from the above discussion that if one drive wheel should come to a soft muddy place in the road where it would meet practically no resistance, that the effect of the differential gear would be to cause it to revolve while the other one would stand still. The result would be that the wheel in the mud would bury itself deeper the longer it was allowed to run, and the engine would be stuck worse than before.

105 *Locking the Differential Gear.*—In order to overcome the above difficulty, and enable the wheel which is on firm ground to pull the engine out of the mud, a lock pin is provided which locks the different parts of the differential gear together and compels both road wheels to move uniformly together. The exact location of this locking device varies in different machines but can be easily found and recognized.

106 *Other Differential Gears.*—In addition to the differential gear above described having bevel gears and bevel pinions, there are other types in which spur gears are used throughout, such as the ones depicted in figures 121 and 122, but the resultant action, nevertheless, is just the same as though

bevel gears were used. The gear shown in figure 121 has one notable advantage, which, by the way, is found in other makes also, and that is that it is enclosed in a tight case which prevents sand and dirt from entering and cutting out

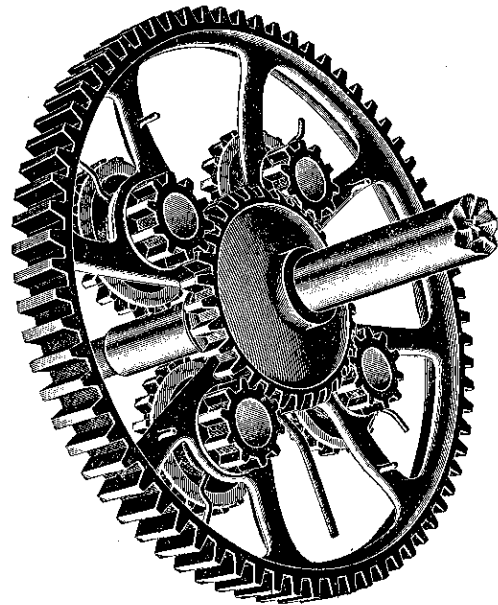


Differential Gear with Spur Pinions and Dust-Proof Case. Fig. 121.

the pinions. It is also provided with a locking cam shown in the figure, whereby it may be locked through means of a lever extending back to the rear of the engine.

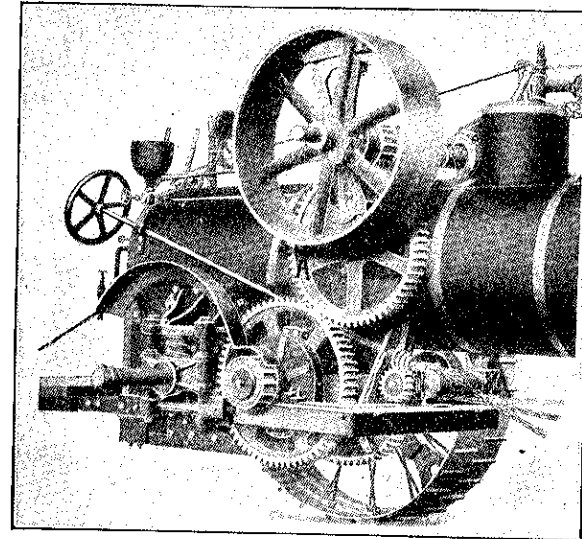
107 *Reasons for Gears Wearing Out.*—There are several rea-

sons why gears wear out rapidly, namely bad alignment, due to faulty work in assembling, bad alignment due to the springing and twisting of the engine, and sand and dirt between the teeth. The first cause, it is a pleasure to



Differential Gear with Spur Pinions. Fig. 122.

acknowledge, is not a very prevalent one and is becoming less every year as the manufacturers take more pains to improve their methods of work. The second cause differs in degree in different makes and in less where especial



Driving Gear Train, Steering Gear, Stub Axle, Spring Mtg. Frame for Countershaft. Fig. 123.

means are provided to stiffen those parts of the machine to which the gearing is attached.

108 The third cause differs greatly in degree also, depending upon the character of the work being done and the kind of ground the engine is working over. It is greater where the ground is dry and sandy than on ground free from grit.

109 *Steering Gears.*—In the majority of traction engines the steering gear consists of two chains, fastened to each end of the front axle, while the other ends are attached to a winding drum in such a way that when one winds on the

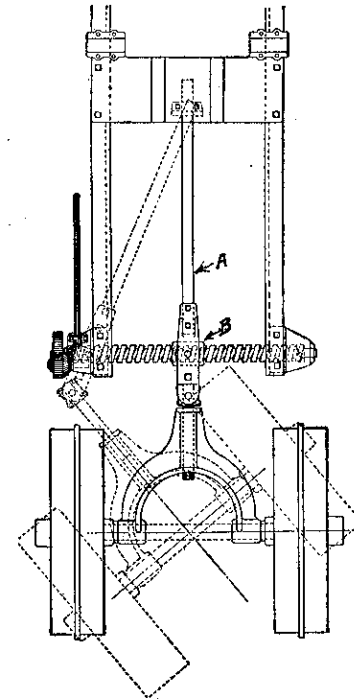
other unwinds. This drum is actuated by means of a worm and worm wheel. The worm wheel is fastened to the end of the drum and the worm to the end of a long rod which extends back to the engineer's platform. The end of this rod is provided with a hand wheel which enables the engineer to turn it either to the right or to the left.

110 The chain should be wound on the drum in such a way that turning the hand wheel to the left turns the engine to the left, and vice versa. This type of steering gear is illustrated in figure 123. On most engines the steering wheel is located on the right or band wheel side of the engine where it is convenient for the engineer in lining up to the separator. Some engines, however, are arranged with a worm wheel on each end of the chain roller so that the steering wheel may be easily changed to the opposite side, where it occupies a more convenient position for handling the engine in certain kinds of work such as grading, ditching, etc.

111 The chains should be kept moderately tight, otherwise when one of the wheels meets an obstruction in the road the engine will be thrown out of its course. Most young engineers make the mistake of steering too much, that is, they whirl the steering wheel around too far to make a slight turn, and then have to whirl it back again to get the engine on its course, while the experienced engineer will not turn the wheel more than is absolutely necessary. It is much easier to turn the front wheels when the engine is moving than when standing still.

112 Another type of steering gear which has been brought

out by one of the large manufacturers recently is shown in figure 124. Instead of a drum and chains to throw the front wheels around, a large screw is provided extending



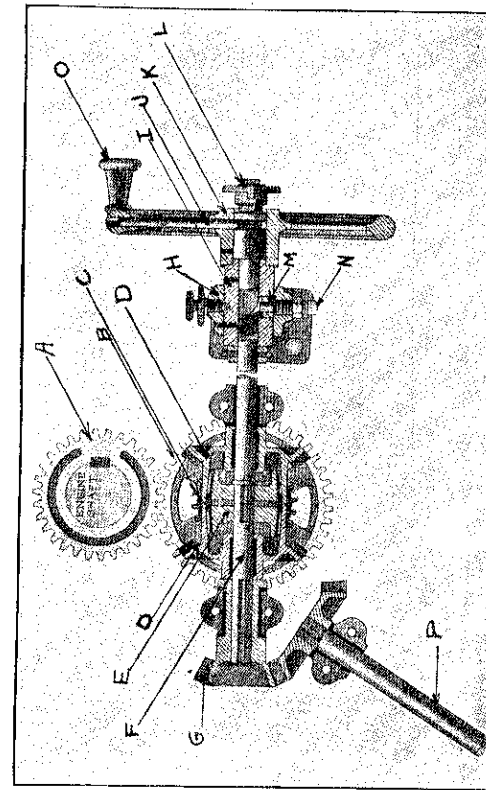
Steering Gear with Screw and Nut. Fig. 124.

crosswise of the frame of the boiler. This screw engages with the nut B which is attached to the reach rod A. When the screw is rotated the nut travels either to the right or

left, depending upon the direction of rotation, and the front wheels are turned either to the right or to the left. In this type of steering gear the wheels are held more rigidly on their course than with the use of chains.

113 *Power Steering Gears.*—Some of the large freighting engines and almost all road rollers are provided with power steering gears. These consist of an arrangement whereby power from the main shaft may be transmitted through suitable gearing to the steering mechanism, thereby enabling the engineer to steer the engine by simply operating a lever or hand wheel. A cut and description of one form of a device of this kind follows. See Fig. 125.

114 A is the gear on the engine shaft, driving B, an intermediate, to which is attached a bevel gear C. This in turn rotates the two bevel gears D, which are provided with conical sockets into which the double cone sleeve E may be slid. As the two bevel gears D revolve in opposite directions, it is plain that when the cone is pushed into the one, the motion of the shaft F is just the reverse of what it would be when the cone is slid into the other socket. When the hand wheel O is in the position shown in the cut it rotates the sleeve H and that being provided with a helical slot M into which the pin N is fitted, this pin being fastened to shaft F, it follows that when the sleeve H is turned either one way or the other it pushes the shaft F either forward or backward and with it the double cone sleeve E, causing it to engage the bevel gears D. The amount of movement of the hand wheel O from one direction to the other is about 45°.

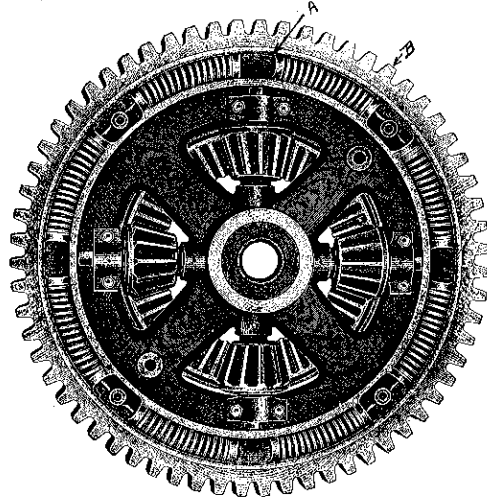


Power Steering Device. Fig. 125.

115 When it is desired to steer by hand the hand wheel O is released from its position by lifting the pin J, and then sliding the hand wheel back against the washer L. The hand wheel may be released from the sleeve H and rigidly con-

nected to the shaft F. It may then be turned backward or forward to operate the steering roll in the usual way by means of a worm on the lower end of rod P.

- 116 *Cushion Gears.*—Where springs are used in the gearing they are placed in the differential gear. See Fig. 126. This gear is made up of a large spur gear having in the middle

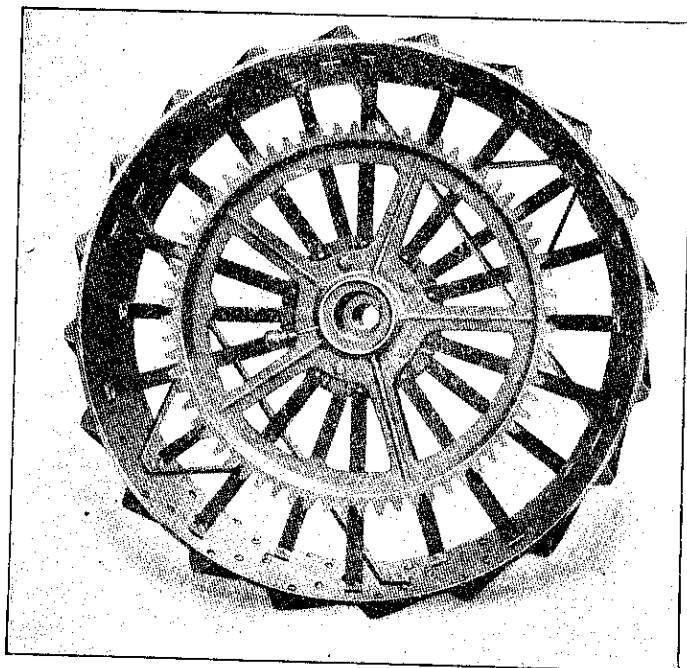


Cushion Spring Gear. Fig. 126.

a casting which contains 3 or 4 bevel pinions. The section containing the bevel pinions is provided with lugs A, which fit in between the sections of the spiral springs, thus the motion is transmitted from the outside gear B, through the springs to the inner portion containing the bevel pinions, and thence to the countershaft of the engine. With this

arrangement any sudden starting of the engine in either direction, which would naturally come as a shock upon the gear teeth, will be taken up in the springs. Quite a good many of the traction engine manufacturers provide their engines with cushion gears, while others dispense with them entirely.

- 117 *Oiling the Gears.*—As a general principle all gears should be oiled to prevent them from wearing. Consequently it is becoming the custom among manufacturers to provide their heavy engines with an oil reservoir on top of the boiler having small oil pipes leading to the different gears, thus providing them with a continuous supply of oil. However, where the soil is sandy the oil often serves to collect particles of sand which may defeat the very object for which oiling is provided. It is better, therefore, for the engineer to exercise his judgment and either use oil or not as the circumstances seem to warrant.
- 118 *Drive Wheels.*—Almost every manufacturer of traction engines has a style of drive wheel peculiar to his engine, which he makes a "talking point" in selling his goods. Consequently it will be impossible to describe all of them.
- 119 Steel wheels are made with a steel rim and steel spokes; cast wheels, usually with a chilled cast iron rim, and either steel or wrought iron spokes. Both types of wheels are in general use, both have given satisfaction, and both have points of merit peculiar to themselves.
- 120 The steel rim wheel is much lighter than the cast wheel, and there is no danger of a crack or break occurring in the rim, even with the hardest usage. These wheels combine



Drive Wheel with Flat Spokes. Fig. 127.

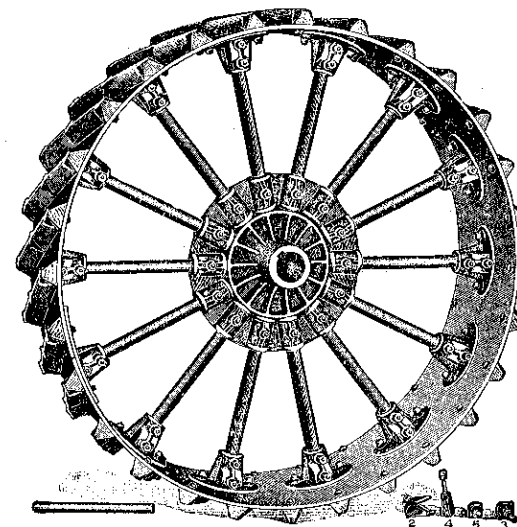
great strength and lightness of weight, two desirable features in a traction engine wheel.

121 The spokes are sometimes made flat, and upset at the outer end, to facilitate riveting to the rim, and sometimes made round.

122 Figure 127 shows the construction of a steel wheel with

flat spokes. Particular attention is directed to the method of securing and inserting the spokes.

123 Another type of steel wheel is shown in figure 128, having round hollow steel spokes secured to the rim, and to



Drive Wheel with Steel Rim and Round Hollow Steel Spokes. Fig. 128.

the hub in a rather peculiar manner, which is clearly brought out in the engraving.

124 Heavier wheels made in this style are provided with two rows of spokes. The grouters on steel wheels are made of cast iron and riveted to the rim.

125 Various forms are given to these grouters, and they are

placed upon the wheel in different ways, some extending straight across, and some diagonally. In many instances two rows of grouters, one on each side of the rim, and placed diagonally so that opposite pairs form a V, toward the center of the rim, are riveted in position. The object of the grouters of course is to prevent the wheel from slipping.

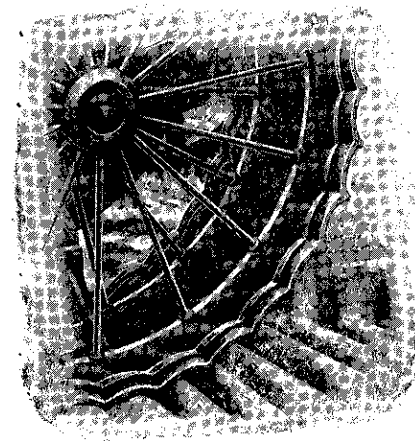
126 A, cast iron drive wheel is made the subject of illustration in figure 129. This wheel is provided with a cast iron grouter, cast as a part of the rim, having a peculiar shape designed for the purpose of making the wheel self-cleaning in muddy ground. To a certain extent there is no doubt that this object has been accomplished, but so far as known no wheel has yet been invented or probably ever will be, that will be self-cleaning when the mud is stiff and sticky.

127 The principal advantages gained in using cast iron wheels are that the rims are stiff and do not spring and that they do not wear in sharp gravelly soil, especially if they are chilled.

128 *The Width of Drive Wheels* varies with the size and weight of the engine. For engines weighing between 10 and 12 tons the usual width is from 24 to 28 inches. Heavier engines are provided with standard wheels as much as 30 inches in width. Where these engines are used for plowing the wheels are fitted in such a way that an extension rim can be bolted to them, increasing the width from 12 to 15 inches. These extension rims are usually found necessary in order to keep the engine from settling too deep in

the ground in stubble plowing or in places where the soil is wet.

129 *Mud Hooks* consist usually of large cast-iron spikes five or six inches high, which may be bolted to the rims of the drive wheels. They are used in soft muddy ground and are supposed to penetrate to the solid ground below, where they will obtain a secure footing.

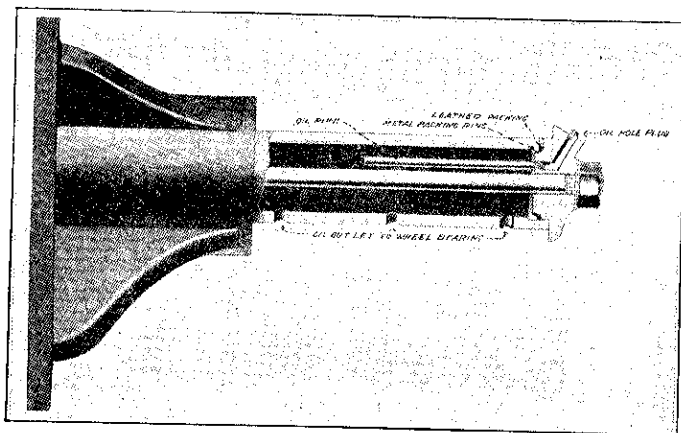


Cast Iron Drive Wheel. Fig. 129.

130 *Front Wheels.*—The only thing necessary to explain about these wheels is the construction of the rim, which is provided with a central ridge from one inch to one and one-half inches high to keep the wheel from slipping side-wise.

131 *Drive Wheel Axles.*—Here again the inventor has given

us a good many different styles to choose from, all of which have considerable merit. Some axles are made straight and solid, some have the outer end made of smaller diameter than the inner, with a square shoulder between the two parts of different diameter, while others again are made hollow, and are provided with oil holes opening into



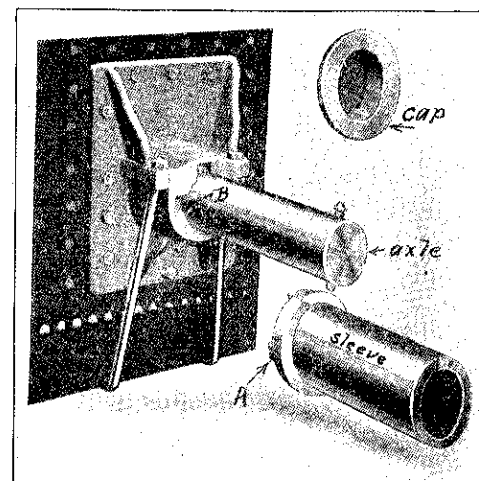
Hollow Spindle—Stub Axle. Fig. 130.

the interior whereby they may be oiled from the inside through a pipe extending to the outer end of the axle.

132 By glancing back over the cuts which illustrate the different types of mounting, several different styles of axles will be seen. They are simple in construction and need no detailed explanation.

133 Fig. 130 illustrates a hollow axle which has been used

on one of the leading styles of traction engines for a good many years with a great deal of success. It makes provision for supplying oil to all parts of the bearing surface continuously, through a small pipe which leads into the interior of the spindle. This matter of oiling the axles is an important one in machines as large and heavy as traction engines, and which are subject to such hard usage.



Stub Axle with Sleeve. Fig. 131.

Figs. 131 and 132 represent another entirely different type of axle which is fitted with a sleeve having a collar on the inner end provided with projections, shown at A, in the figure, which fits into corresponding notches B, in the bracket, thus holding the sleeve in position. A cap fits

over the end of the axle and is held in place by a pin. The wheel revolves upon the sleeve while the sleeve remains stationary upon the axle. All the wear, therefore, comes upon the under part of the sleeve. The manufacturers claim that when this sleeve becomes worn it may be taken out and turned half way around and becomes just

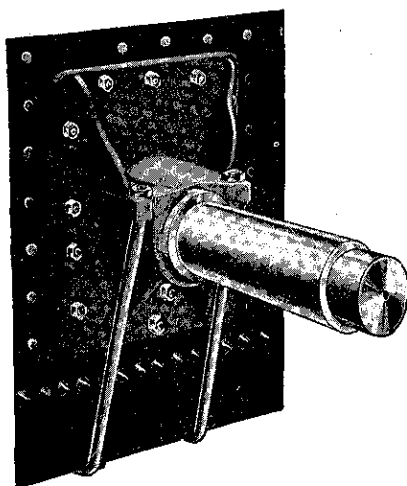


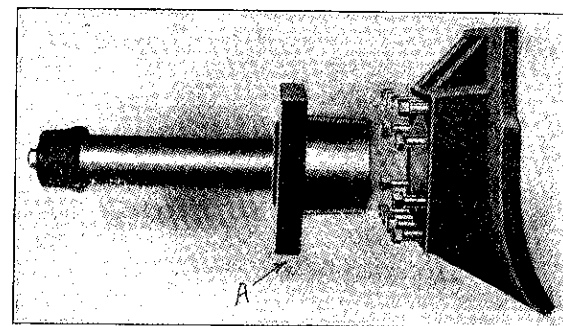
Fig. 132.

as good as new. At any rate, when too much lost motion occurs at this point, it is easy to make repairs by taking out the old sleeve and putting a new one in its place.

- 134 Still another type of driving wheel axle is represented in the following illustration, Fig. 133. Like the one illustrated in Fig. 130, it is also made hollow but differs con-

siderably in the way it is attached to the main bracket. A large tapered portion fits into an accurately bored hole in the bracket and is held in place by a number of stud bolts which pass through flange A and draw the axle and casting B tightly together.

- 135 In all engines having stub axles the axle remains stationary while the wheel revolves, but in rear mounted engines it is the general custom to mount the axle in a long



Another Type of Stub Axle. Fig. 133.

bearing. One drive wheel is secured to the axle, while the other is allowed to run free on the axle. When it is desired to lock both wheels in case one sinks into a soft spot in the road, provision is made to secure the free wheel to its axle by means of a pin instead of locking the differential gear.

- 136 The Main Shaft is made of machinery steel, that is, a low carbon steel. It is neither as soft as boiler plate nor as

hard as tool steel. Where an extra good quality of steel is demanded, cold rolled steel shafting is frequently specified. This is harder and much stiffer than ordinary machinery steel, and is better adapted to hard service.

- 137 The speed of the main shaft varies slightly, depending upon the size of the fly wheel, ranging from 230 to 250 revolutions per minutes.
- 138 *The Counter Shaft.*—In past years it has been customary to make the countershaft about the same size or perhaps 1-16 of an inch greater in diameter than the main shaft, and for ordinary work this has been sufficient.
- 139 For heavy road work, however, it is obvious that this is a mistake. Owing to the design of the gearing the countershaft runs only at about one-quarter of the speed of the main shaft. When the engine is hauling all it is able, all of the twisting effort of the fast running main shaft is transmitted to the countershaft, which, running at a much slower rate, must, consequently, be subjected to a much greater twisting stress.
- 140 For this reason the countershaft should be much larger in diameter than the main shaft. The area of the end of the shaft should, in other words, be about as much greater than that of the main shaft as its speed is less, in order to carry the same load.
- 141 *The Front Axle.*—The usual method of constructing the front axle is to enclose a steel shaft in a heavy casting at the central part to carry the turn table for the bracket and knuckle joint supporting the boiler, and then reinforce the whole axle with truss rods underneath. This makes a

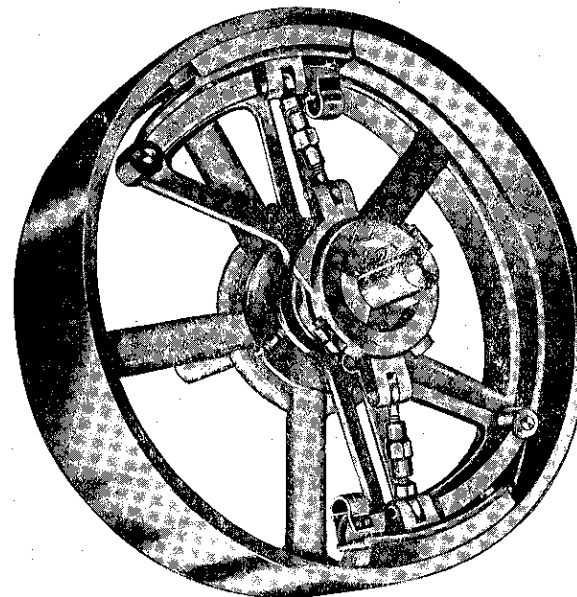
strong serviceable structure. A brace extends from the lower central part of the axle to some convenient point on the boiler to hold it in position.

- 142 *The Knuckle Joint* is formed in a variety of ways; sometimes with a turn table bracket secured to the boiler, resting on balls in a similar turn table on the axle, to which it is secured by means of a king bolt; and sometimes by a simple ball and socket joint also held together with a king bolt.
- 143 *Friction Clutches.*—All single cylinder traction engines and a considerable number of double cylinder engines are provided with some sort of a friction clutch. The object of a friction clutch is to enable the engineer to connect the main shaft to the driving gears at will, and so move the whole machine on the road, or stop it, without stopping the motion of the engine itself.
- 144 In general, a friction clutch consists of a sliding sleeve mounted on the hub of the driving pinion and secured thereto by means of a feather key. This sleeve carries two or more jointed arms which are provided with wood shoes on their outer ends. When the sliding sleeve is pressed over toward the fly wheel the arms straighten and press the shoes firmly against the inside of the rim of the fly wheel. The friction at this point prevents the shoes from slipping and so they, together with the arms and sliding sleeve, revolve with the fly wheel.
- 145 Since this sleeve is attached by means of a key to the driving pinion it must also revolve with the main shaft. Consequently the driving gears are put in motion and the drive wheels move the whole machine either backwards or

forwards, depending upon which way the reverse lever is thrown. The driving pinion is not keyed to the main shaft, and can only be made to revolve with it through the friction clutch and fly wheel, or by means of a lock pin which locks the arms of the friction clutch to the fly wheel. Running in this way is sometimes spoken of as running with a "stiff gear."

- 146 *Discussion of Friction Clutches.*—A friction clutch is very desirable on all single cylinder engines, as it gives the engineer instant control over the road movement of his engine and enables him to back into the belt, when belting to the separator.
- 147 There seems to be room yet for improvement in a good many clutches, judging from the way they sometimes act. A good clutch will engage with the fly wheel readily, and what is of much more consequence, will let go just as soon as it is released.
- 148 Here is where the difficulty arises. They do not always let go when thrown out. This failure has been responsible for accident and even death to a great many men.
- 149 The reasons, apparently, that a clutch sometimes fails to release, may be due to a faulty adjustment of the shoes or to centrifugal action. The rather heavy clutch shoes revolving at the same speed as the fly wheel have a tendency, due to this motion, to fly out against the rim of the fly wheel. If the clutch lever does not pull these shoes entirely free and lock the clutch to the driving pinion, the centrifugal action will hold them engaged and the engine will not stop.

- 150 Clutches are built in a variety of ways. Some are provided with two shoes and some with three. Figs. 134 and 135 show to rather common styles, and Fig. 136, a clutch

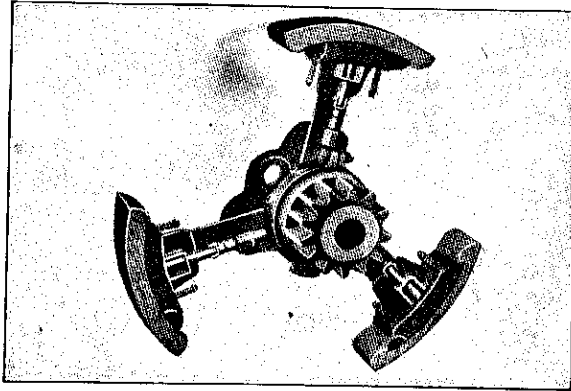


Friction Clutch with Two Shoes. Fig. 134.

in which a counter balance is provided with the object of overcoming centrifugal action.

- 151 *Putting Double Engines in Gear.*—This is accomplished in two ways, depending upon the design of the engine. One way is to use a friction clutch just as in simple or tandem compound engines, and another is to secure the driv-

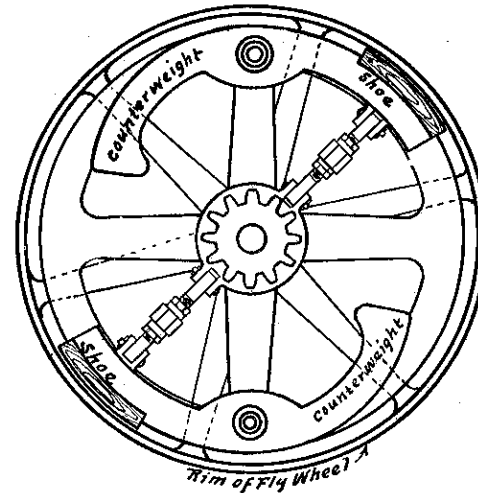
ing pinion to the main shaft by means of a pin. Both methods are satisfactory and both are in use at the present time. Those who adhere to the clutch method claim it is better not to have a perfectly rigid connection between the engine and drive wheels, claiming safety on the grounds



Friction Clutch with Three Shoes. Fig. 135.

that under very heavy stress the clutch will slip and prevent breakage. They furthermore claim that the clutch gives better control of the engine since it may be engaged or disengaged while the machinery is running, thus throwing the traction in or out as the occasion demands.

152 The adherents of the other idea claim that a clutch only adds more parts which are apt to get out of order, without introducing any positive advantages. Their claim is based on the fact that a double engine may be started or



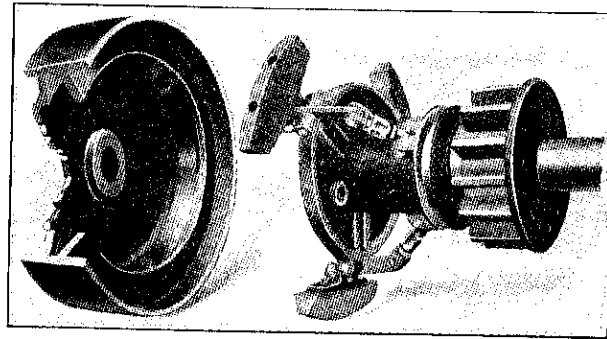
Counterbalanced Friction Clutch. Fig. 136.

stopped slowly while pulling a heavy load without danger of getting on dead centre. Then, when the machine is in position, the engine may be stopped and the pin quickly disengaged, thus putting the engine in order for running in the belt. The necessity for a clutch is not so great on a double engine because it may be moved as much or as little as desired and as fast or as slowly as desired by the proper use of the throttle.

153 The two following illustrations, Figs. 137 and 138, represent two kinds of clutches used on double engines. Fig. 137 shows a friction clutch mounted on the opposite end of the main shaft from the fly wheel. Fig. 138 represents

a pin clutch. The pin is held normally in place by a spiral spring when in position for driving. A lever handle on the outer end of the pin slides over a spiral cam and withdraws the pin from the driving pinion and at the same time compresses the spring.

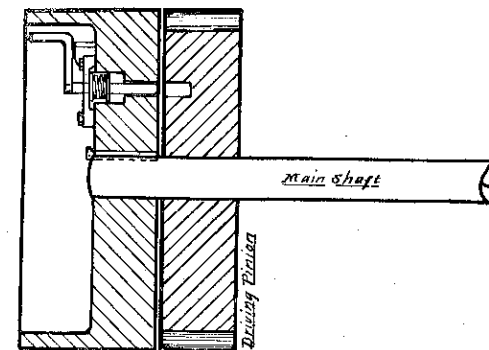
- 154 *Method of Adjusting Clutch Shoes.*—Perhaps the simplest method is to turn the adjusting nuts back until, when



Our Style of Friction Clutch Used on Double Engine. Fig. 137.

the clutch lever is in position to engage the shoes, they do not touch the wheel. Then with the clutch lever still in, set each shoe out until it just touches the wheel. Now turn each adjusting nut the same distance, and set the shoes out as far as desired. They will both bear evenly on the wheel if the work is done carefully and be in less danger of either slipping or sticking than if they bore against the wheel unequally.

- 155 *Winding Drums.*—Quite a good many traction engines,

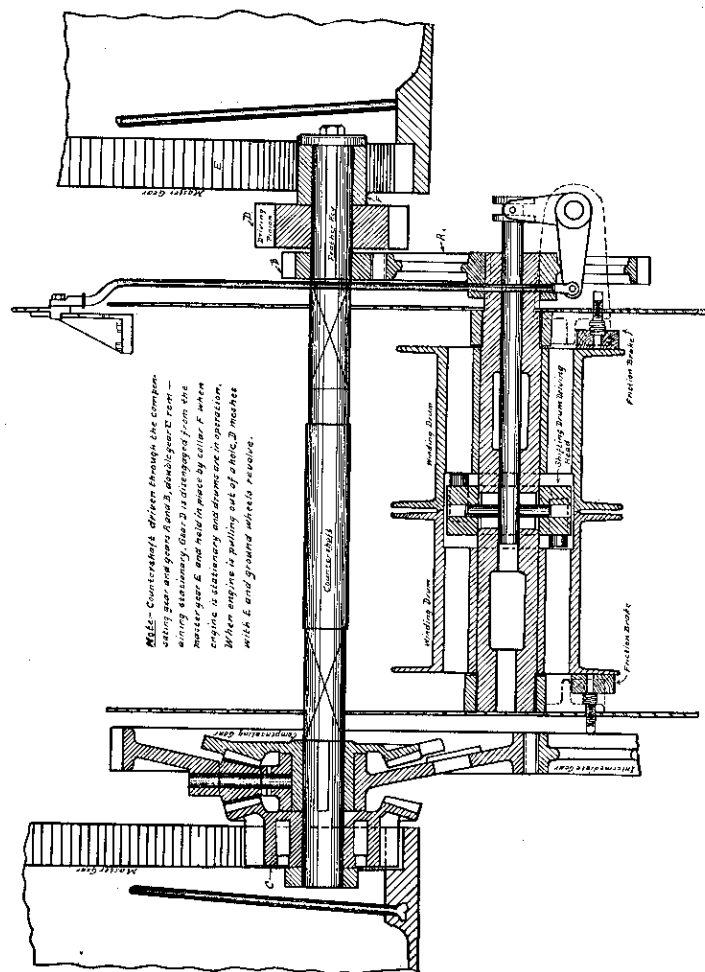


Pin Clutch Used on Double Engine. Fig. 138.

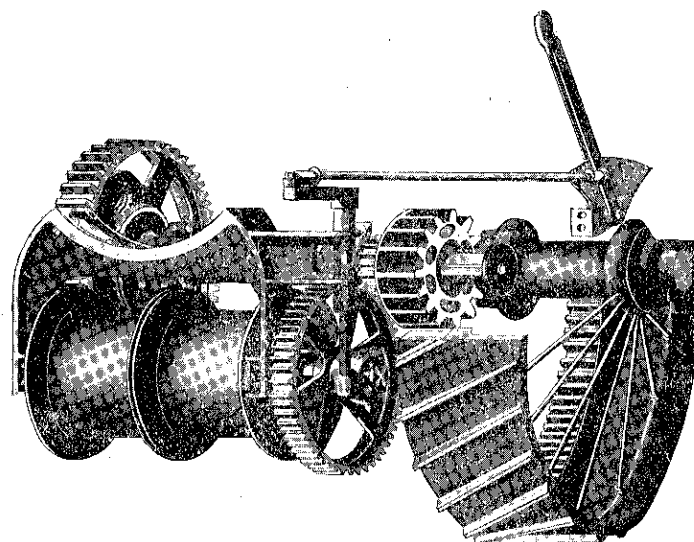
especially the large sized ones which are used for freight-ing purposes, are equipped with what is called a winding or hauling drum attachment. Engines so equipped can be used as hoisting engines or for any purpose where it is desirable to use a long cable for hauling, the engine, of course, remaining stationary.

- 156 Winding drums are made in a variety of styles, some with the axle horizontal, and others with the axle vertical. Figures 139 and 140 represent a hauling attachment used by one of the prominent traction engine companies of this country.

- 157 In this case two drums are provided, mounted upon an axis and driven through suitable gearing from the engine countershaft. When used simply for hauling or hoisting purposes the driving pinion is slipped out of mesh with the master wheel and locked in this position. At the same



Sectional Drawings of Winding Drum. Fig. 139.

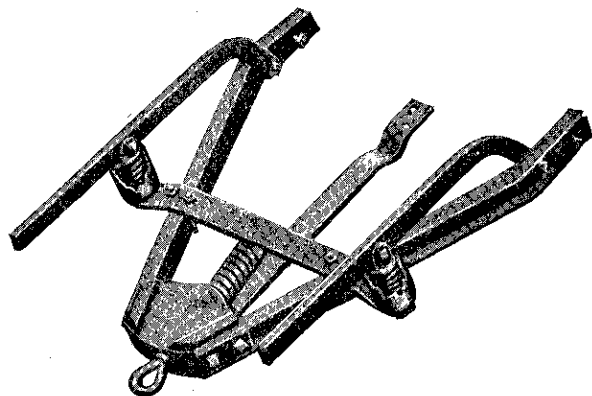


Perspective of Winding Drum Attachment Shown in Fig. 139. Fig. 140.

time the gear which drives the winding drum is made to engage with the driving drum gear. When the winding drum is used to help pull the engine out of the mud, as it sometimes is, the cable is run out and anchored to some secure support ahead of the engine. The driving pinion is made to mesh with the master wheel, and thus both the drum and driving gears work together to pull the engine out on solid ground.

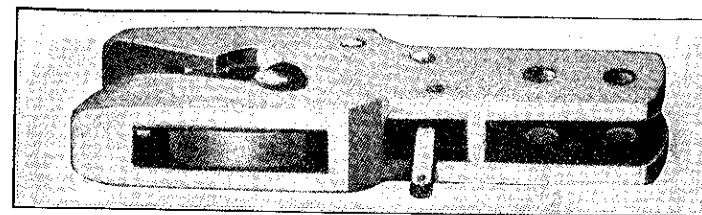
158 The notes accompanying the sectional drawing, Fig. 139, should make the construction of this attachment plain without further explanation.

- 159 *Draw Bars.*—Every traction engine must be provided with a framework attached either to the boiler, or to the rear axle or both, to provide an attachment for coupling up to the tender, separator, or whatever the operator wishes to hitch to. This framework is usually made of flat bars of wrought iron or steel bolted to the sides of the firebox in engines designed for heavy work. These draw bars are



Draw Bar. Fig. 141.

made extra heavy, and long enough to reach the entire length of the firebox. The bar to which the object to be hauled is attached is, in the majority of instances, provided with a heavy compression spring to relieve the engine from sudden shock or jar. These draw bars are made in quite a variety of styles, depending upon whether the engine is used for threshing, plowing or freighting. Fig. 141 represents the essential features of draw bar construction.



Automatic Coupler. Fig. 142.

- Draw bars not only serve as a means of connection between the engine and the object hauled, but also act as a support for the engineer's platform and perhaps the water tank.
- 160 *Automatic Couplers.*—Quite a number of manufacturers provide their engines with automatic couplers which enable them to hitch to the separator or other object without the use of the cumbersome link and pin. These couplers act on the same general principle as car couplers and are easier to handle, quicker, and cause less danger to the operator than the old pin couplers. There are several forms of automatic couplers on the market which are made to attach to any engine and which are quite moderate in price. See Fig. 142.

QUESTIONS.

1. Name the different types of mounting.
2. Name the advantages gained in using the boiler as frame work.
3. Mention the advantages gained in using an independent frame work for the boiler and engine.
4. Explain what is meant by the term spring mounting.

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5. Explain the influence of the distribution of weight on the pulling power of an engine.
6. Describe two styles of rear mounting.
7. Explain what is meant by stub axle mounting.
8. Describe one style of stub axle mounting with springs.
9. Explain two different styles of independent frame work.
10. What is meant by (a) a simple train of gears, and (b) a compound train of gears.
11. State a rule for finding the speed of the last gear in a simple train of gears.
12. State a rule for figuring the speed of the last gear in a compound train of gears.
13. Knowing the speed of the worm, and the number of teeth in the worm wheel, how do you figure the speed of the worm wheel?
14. Explain how to find the road speed of an engine when the number of teeth in each of the driving gears is known and the speed of the engine.
15. Explain the action of the differential gear.
16. Should driving gears be oiled?
17. Describe one style of cushion gear.
18. Describe two types of driving wheels.
19. Describe three styles of driving wheel axles.
20. Show how motion is transmitted from the engine to the driving gears.
21. Describe a method for adjusting friction clutch shoes.

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LESSON WITH QUESTIONS

PART VII
OPERATING THE BOILER

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3. Before answering the questions carefully review the entire subject.
4. In answering do not write the questions—merely use their numbers.
5. Answers **MUST** be written on good white paper, in ink, and only on one side of the sheet.
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LESSON VII.

MANAGING A TRACTION ENGINE.

- 1** *Taking out a New Engine.* All boilers and engines are put in proper shape, steamed up, and tested before leaving the factory and all necessary adjustments are made at this time before they are approved by the company's expert. After having been tested thoroughly they are prepared for shipment. All of the brasses are removed, together with the pumps and injectors and other parts which might be damaged in shipment. These parts are boxed up and are accompanied with an invoice sheet which shows all the tools and fittings which should accompany the machine. When the engine arrives at its destination and it has been unloaded and settled for, the purchaser should go over this list carefully with the company's expert and check every article. If anything is missing the fact should be reported to the company's nearest branch house at once in accordance with the regulations which are perscribed in such cases. The company always stands ready to make good any loss or breakage during shipment, provided the fact is made known to them at once and in proper form.
- 2** *Unloading an Engine from the Cars.* The company usually sends out an expert from their nearest branch house

to take charge of unloading the rig from the cars and putting it in proper running order. This is generally to the advantage of the purchaser, as the expert will be familiar with the best ways and means of unloading and can complete the work with the least waste of time. He is also familiar with all parts and knows exactly how to examine the engine for breakages due to faulty handling in transit. The expert, moreover, who is usually a competent man, can give the purchaser information at this time in regard to the proper handling of the machine and also make him acquainted with all of its parts and features of construction which need especial care. Furthermore, the purchaser is relieved of the responsibility of putting the machine in proper running order.

- 3 In unloading one of the large sized engines it is necessary, unless the car happens to be at a station where provision has been made for this sort of business, to build a strong substantial platform extending from the level of the car down to the ground. This platform should be made of heavy timbers, and supported at intervals by proper supports, so that there will be no danger of its either breaking down or falling down under the weight of the engine. Sometimes at out of the way stations a pile of railroad ties are piled up at the end of the car and the engine run down over them. Such a platform is not very safe and should not be used unless nothing else can be found. Before moving the engine, the car brake should be set to prevent it from moving when the engine starts down the platform.
- 4 Sometimes the engine is unloaded by hand, and some-

times steamed up and run off the car with its own power. When the task is performed by hand the friction clutch is thrown in and a rope wound around the fly wheel. Three or four men pulling on this rope can move the engine in this way, and with another man at the steering wheel the job can be accomplished in a satisfactory manner. If the engine is not supplied with a brake the cylinder cocks may be closed and the compression of air in the cylinder made use of to prevent the engine from running too fast down the incline. It is more satisfactory in most cases to steam the engine up and run it off with its own power. This gives the engineer perfect control of the engine. If it starts to run of its own weight he can stop by reversing the engine and thus go as slow or as fast as he chooses. It is quite customary to unload engines in this way and at the same time unload the separator by hitching it behind the engine. In fact, where the whole rig is sent out loaded on the same car, it is customary to load them in such a way that they may be unloaded in this manner.

- 5 *Precautions with a New Engine.* Most engines and separators have to be shipped by rail a considerable distance before they reach their destination. They are loaded upon open flat cars where they are exposed to dust and the cinders from the locomotive. These cinders lodge in every available place about the engine and separator, and unless precautions have been taken at the factory, some of them are very apt to find their way into the bearings. If this happens to be the case, and care has not been taken to clean the bearings thoroughly when the machinery is first taken

out, there is sure to be trouble with hot boxes. It seems advisable, therefore, in taking out a machine that has made a long journey by rail, to examine all the bearings carefully before starting, to make certain that no cinders or dirt has lodged in the oil pockets or any place where they can get into the bearings. Proper care in this matter will prevent a great deal of trouble with hot boxes on new machines.

- 6 *Filling the Boiler.* Traction engine boilers are usually provided with a filling plug on the top of the boiler, which may be unscrewed, and the opening fitted with a funnel through which water may be introduced into the boiler. If a filling plug is not provided, the whistle or pop valve may be unscrewed and the boiler filled at this point. A tank pump, which is a part of the proper equipment of the water tank, is used for pumping the water into the boiler. When about two inches show in the glass, examination should be made to find out how much water there is above the crown sheet or above the top row of flues. This will test the location of the glass. The engineer will thus be certain when he sees an inch of water in the glass just how much water there is above the crown sheet. The position of the gage cocks with reference to the water level can be ascertained at the same time. If both of these tests are made the engineer will know with absolute certainty exactly where the danger level of the water is with reference to both the gage glass and the gage cocks.

- 7 *Raising Steam after the Boiler has been Filled.* The fires should be started and steam raised slowly. While the pres-

sure is coming up the engineer should examine all pipe connections and observe if any leaks appear at the hand holes or any other place. If a leak is discovered, the tightening up of a nut or a packing gland, will usually stop the leak and put the engine in proper shape for running. The same precaution should be taken when steam is first turned into the cylinder to note whether the steam chest covers, cylinder head, and all other parts having a packed joint are screwed up tightly and do not leak. If all these precautions are taken there is not very much danger of packing blowing out at any of the joints after the engine has started to work.

- 8 *Steam Pressure.* After the steam pressure has risen to 50 or 60 pounds it is advisable to try the safety valve and make sure that it is working. Then try the pump and injector, or both of them, to make sure that they are in perfect working order, and that the check valve on the delivery pipe is working. The action of the latter can be determined by listening to it. If it is working all right a sharp clicking noise will be heard whenever the pump makes a stroke. The gage cocks and gage glass cocks should also be tested to make sure that they are in good working order.
- 9 The pressure which the boiler should carry is usually specified in the builder's catalogues and if the pop valve does not act when the pressure rises to the proper point it is pretty good evidence that the steam gage is out of order or that the pop valve is not properly adjusted. The latter difficulty, however, is one that is rarely met with, and the

difficulty will most likely be found in the steam gage. In either event, it is the engineer's duty to locate the trouble and remedy it without delay.

- 10 The steam pressure should be maintained as near constant as possible and just a little below the point at which the pop valve is set. To do this, requires good firing, and a proper manipulation of the dampers. It is necessary to maintain a constant steam pressure in order to have a steady source of power with which to keep the engine running at a uniform rate of speed. If the pressure varies a considerable amount, the speed of the engine will also vary to some extent, in spite of the fact that it is equipped with a governor which is designed to maintain the speed at a constant value. A change in the pressure of the steam means also a change in the temperature of the boiler. If the temperature of the boiler fluctuates widely, and repeatedly, it has a deteriorating effect upon the metal. It is a well known fact that sudden changes of temperature has a tendency to crystallize both iron and steel and thus weaken them. For these reasons, therefore, the steam pressure should be kept as nearly uniform as possible.

- 11 *Methods of Regulating the Steam Pressure.* In firing with straw there is usually very little danger of having trouble with the steam pressure rising too high. If there is, a little slower firing, or the shutting of the draft doors will remedy the difficulty. In firing with coal, however, it frequently happens that the heat in the fire box will become very intense with a heavy fire. If the engine is not running with a full load the steam pressure will rise and the pop valve

will be blowing off at very frequent intervals. The same thing will happen also when the engine is stopped. The best way to reduce the pressure is to close the draft doors and start either the pump or the injector. The pumping of cold water into the boiler will reduce the pressure therein sufficiently to keep the pop valve from blowing off. Sometimes the fire door may be opened a small amount to keep the steam pressure from rising. This admits cold air over the fire and tends to deaden it. If the door is not opened wide, and the engine is not running, this method is not very objectionable, but it should never be done when the engine *is running* because the draft in the smoke stack, due to the exhaust, will draw cold air rapidly through the flues and chill them, thus causing them to leak. The flues being comparatively thin are quickly heated or quickly cooled and so expand or contract and work loose in the flue sheets and leak unless care is taken to prevent sudden large changes in temperature.

- 12 *Low Water.* Water should never be allowed to get so low in the boiler that it cannot be seen plainly in the glass or so low that the crown sheet will become uncovered. However, it sometimes happens that an accident will happen to the tank man, preventing him from getting back to the engine, when he is expected. The engineer, expecting him every moment, may run until the water becomes dangerously low. In this case, if he is very sure that the water has not dropped below the crown sheet, he should keep on running, because the agitation of the water when the engine is in motion, keeps it moving over the heated sur-

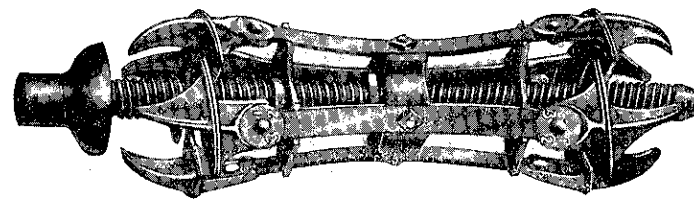
faces and there is not as much danger as if he stopped entirely. If the tank man is not in sight by this time the proper thing to do is to deaden the fire by throwing on dirt or wet ashes. Drawing the fire when the water gets low is not a good plan, because, doing so, will increase the temperature in the fire box momentarily, and may cause disaster to the boiler. Never throw water on a fire in the fire box to deaden the fire.

- 13 *The Duty of the Fireman in the morning.* The fireman is the first man at the engine in the morning and it is his duty to get up steam and have the engine in readiness to start at the appointed time. On coming to the engine he should first open the gage cocks on the gage glass and make sure how much water there is in the boiler. He should also try the gage cocks to see that they correspond with the glass. He should then rake out the ashes from the fire box and clean the flues. The next thing to do is to start the fire and get up steam. If there is enough water in the boiler, and there should be if it has been left in proper shape the night before, he should open the bottom blow off valve and drain some of the water out of the boiler. The object of doing this is to clean out whatever mud and sediment may have settled during the night. When letting water out of the boiler the fireman should stay by the blow off valve and be absolutely certain that it is not drawing off too much water and thus allow the water level to fall too low in the boiler.

- 14 *Cleaning Flues.* The flues should be cleaned with a good flue cleaner that will scrape all the soot out of the inside

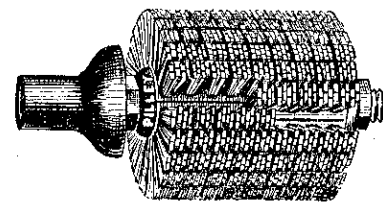
OPERATING THE BOILER.

of the flues. Soot is a very good insulator and if not cleaned out frequently, will make firing very difficult, and make it almost impossible to keep up steam. In a recently conducted test on a boiler in which the flues had not been



Flue Scraper. Fig. 143.

cleaned for three days, it took almost three hours to get up steam, with coal for fuel. After cleaning the flues steam was raised in less than one hour. The flues should always be cleaned before the fire is built in the morning, and



Flue Scraper. Fig. 144.

again at noon if they are at all dirty.

- 15 Figures 143 and 144 represent two different styles of flue cleaners; both of which will do satisfactory work when new. After using for some time, the wires in figure 144 be-

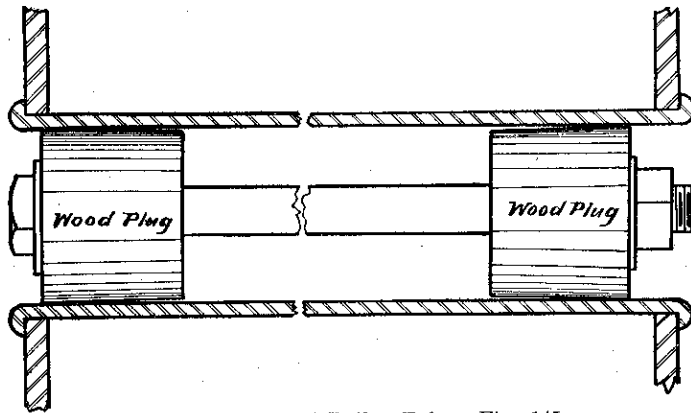
come worn and the brush is useless. For general purposes, therefore, the one shown in figure 143 is preferable. It is constructed in such a way that screwing in the rod will extend the jaws and thus make provision for any wear that may occur. When the flanges which rub against the inside of the flue are worn off, the cleaner is worthless and a new one must be purchased. It does not pay to use a worn out flue cleaner.

- 16 *Duty of the Fireman at Night.* When the engine is shut down at night the water should be pumped up so there are 4 or 5 inches in the glass. This will reduce the boiler pressure and even if there is considerable fire in the fire box there is no danger of the water getting low before morning.
- 17 If the weather is cold, or, if the engine is in a section of the country where frost occurs, all connections in which water may have accumulated should be drained in order to prevent damage to the pipes or valves on account of frost. If the fireman or engineer will adopt a system in draining connections, there will be no danger of forgetting any part. A good plan to follow is to start with the gage glass. After water has been pumped up to the proper height in the boiler, close both the upper and lower valves and open the drain cock at the bottom of the glass. Then drain the pumps and cylinders both at the steam end and at the water end. If a lubricator is used, this is the next point to look after. Then go around the boiler and drain the feed pipe, close the shut off valve on the delivery pipe where it enters the boiler, drain the check valve in the delivery pipe, and then

open the drain cock in the steam chest. The next thing to attend to is to close the globe valve in the main steam pipe. that is, if there is one, and then drain the throttle valve. The cylinder cocks, of course, are always opened when the engine is stopped. If all of these things are attended to every night, whether the weather is cold or not, there will be no danger of forgetting, or what is worse of having to say the next morning "I did not think it was going to freeze."

- 18 After the engine is drained, it is a good plan, if coal is being used for fuel, to bank the fire. If this is done the steam can be gotten up in a much shorter time next morning.
- 19 *Managing the Fire.* The subject of firing has been discussed in a previous lesson and little need be added in regard to the methods of firing. A few precautions may be mentioned, however, that should always be observed in handling the fires. For example, when using a kind of fuel which throws sparks badly, like certain kinds of wood such as old rails, care should be taken to keep the spark arrester in good order and in its proper position. When ashes are raked out of the fire box they should always be wet down thoroughly to make absolutely certain that there is no danger from fire. This is especially true where straw is used for fuel. The half burned chaff and clinker from a straw fire will retain heat for several days and is quite difficult to quench unless spread out thin and soaked with water.
- 20 *Cleaning the Fire.* This is necessary in using any kind of fuel, but more especially in using either coal or straw. The

ashes and clinker which form in the bottom of the fire clogs the grates, and unless cleaned at frequent intervals air cannot reach the fuel and the fire will be poor. It is necessary therefore, every two or three hours, or sometimes more frequently, depending upon the character of the fuel, to clean the grates. This should be done when the engine is stopped and should be done as quickly as possible to prevent the fire from dying down and thus reducing the boiler pressure.



Plugs for Bursted Boiler Tube. Fig. 145.

The proper method to pursue is to first clean one side by raking the fire up from the grates with the fire hook, pulling out the clinker on one side first, and then clean the opposite side. This work never should be done while the engine is working.

- 21 *A Burst Boiler Flue.* Occasionally a boiler flue will crack and water will spurt out of the boiler and quench the fires.

Where this occurs in the field and there is not time to put in a new flue, repairs can be easily and quite quickly made by driving a pine plug in each end of the broken flue and bolting the two together as shown in figure 145. In fact, it is a good plan to always keep a couple of these plugs in the tool box to be ready for just this emergency.

- 22 *The Tool Box Equipment.* The tools which are furnished with an engine consists of the following: A flue cleaner, poker, oil cans, monkey wrench, and a number of other open wrenches. In addition to these the engineer should provide himself with a good machinist's hammer weighing about $1\frac{1}{2}$ pounds, a combination wrench which can be used on either pipes or nuts, a flue beading tool, a calking tool, a cold chisel, cape chisel, some files, and a number of punches of various sizes. He should also have a couple of good screw drivers, one large, the other small, a pair of pliers, wire cutting pliers 7 or 8 inches long are best—and a set of packing hooks. A man who works around engines for any length of time usually provides himself with a kit of tools which include all of those above mentioned and perhaps a good many more. The outfit herein described will be found adequate for nearly all the work that is necessary to do about a traction engine, and is recommended to the young engineer first starting out.

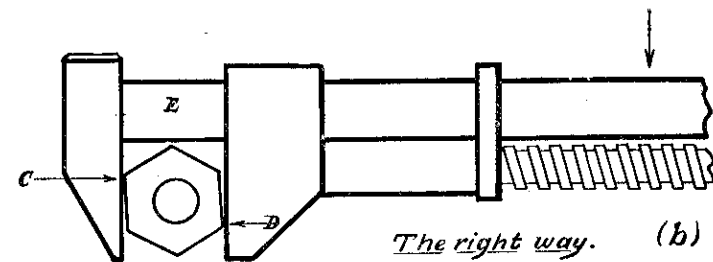
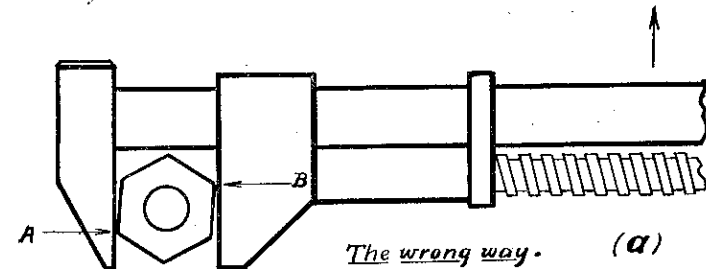
- 23 *Extras Which Should Be Carried In The Tool Box.* In addition to the usual complement of tools which have just been described, a number of extras should be carried with which ordinary repairs can be made in the field. The list of extras which should be carried depends largely upon

the distance from the nearest town. There are some, however, that should always be carried along no matter how quickly repairs can be gotten. The following list may be taken as a guide in making out the list of supplies that should be ordered in starting out at the beginning of the season: A roll of rubber packing about one-sixteenth of an inch thick, to be used to pack the steam chest cover and hand hole plates, a ball of candle wick packing for valve stems, a bundle of cotton waste, two or three extra water gage glasses together with gaskets for the same, several gaskets for packing the water end of the pump plunger, a can of hard oil, a pound of ring packing for the piston rod, a few strips of lace leather for both the governor belt and the main belt, and fifteen or twenty pounds of babbitt. To this list add a good supply of cylinder oil, and perhaps an extra steam gage. The list may be added to as occasion demands, but at least those articles specified above should be found in every well equipped tool box.

- 24 *Cotton Waste.* A bundle of cotton waste costing from 7 to 10 cents per pound is a necessary part of every tool box equipment. By its aid the engineer can keep his engine looking well, and not only that, but he will, as he goes over the machine every day, find those places that need adjustment. Wiping an engine and keeping it looking neat is a good thing in itself because any machine that is kept in good shape lasts longer. But, better than this, it is the surest means of inspection. If the engine is wiped clean every day very few things can start to go wrong without the engineer's finding it out. Furthermore, and not least

by any means, a clean engine is a good advertisement for an engineer. It shows that he is careful, conscientious, and industrious, and that he takes a pride in his work.

- 25 *The Use of the Monkey Wrench.* The stationary jaw of a monkey wrench is weaker than the movable one, because



The Use of the Monkey Wrench. Fig. 146.

the latter has a long bearing surface while the former has only the metal just back of the head to support it. A wrench is weaker between the two heads than anywhere else. In using a wrench, therefore, it should be turned in such a way as to bring the leverage on the long jaw. Both the

right way and the wrong way to use a wrench are illustrated in fig. 146. When the wrench is drawn down upon the nut as shown in *b* the jaws bear at C and at D thus putting the longer leverage upon the movable jaw, and the short leverage on the fixed jaw as it should. In *a* the long leverage comes upon the fixed jaw and the short one on the movable jaw which is wrong. When used in this way the wrench has a tendency to bend at E, its weakest point.

26 The monkey wrench is one of the most useful tools in the tool box, but, nevertheless, it gets a great many young engineers into trouble. It should be used only when necessary. Many men try tightening the nuts on all of the boxes just as soon as they hear a pound or knock. This is wrong. The thing to do is first to locate the knock definitely before trying to cure it. When the trouble is found, then use the monkey wrench, but do not use it to experiment with in the hopes that you will stumble upon the right place.

27 *Engine Cabs.* Quite a good many traction engines are now equipped with either cabs or canopy tops. For ordinary threshing, when the weather is not too cold, a canopy top is sufficient protection for the engineer, while at the same time it affords some protection to the engine from both the sun and the rain. Where an engine is used in the winter time for sawing wood or shelling corn, a cab with side curtains is almost a necessity. It not only protects the engineer and adds to his comfort, but often prevents the steam gage and lubricator from freezing and reduces the loss through radiation. The only objection to its use is that if the engine goes through a bridge, or meets with a serious

accident of a somewhat similar nature, the engineer has less chance of escape than if the platform were open. Accidents of this nature, however, are comparatively rare, and if the engine is to be used late in the fall or in very cold weather it is very much better to provide it with a cab or with a canopy top having side curtains, which can be fastened down at the side.

28 *Boiler Testing.* There are two methods of testing a boiler, namely; the hammer test and the hydrostatic or cold water test. Both methods are used by boiler inspectors. Either, in the hands of a competent man, is fairly satisfactory. In addition to the test the inspector takes account of the age of the boiler, the kind of care it has received, as near as he can ascertain it, and the general appearance of those portions which have been exposed to the fire. Boiler testing, however, is not a very exact thing and depends for its reliability upon the previous training and the good judgment of the inspector.

29 *The Hammer Test* consists in going over every plate and rivet in the boiler and tapping it with the ball pene of a light hammer. If a traction engine is tested in this way the boiler jacket must be removed, consequently this test is seldom applied to traction engine boilers, but is almost always applied to stationary boilers. In making this test the inspector depends upon his ear, and upon the action of the metal under the hammer. The sharp ringing sound of a perfect plate is quite different from one that is cracked or pitted. If the plate is dented, it is evidence that it is thin at that place. All suspected weak plates, including loose

rivets are marked with a piece of chalk and orders given for their repairs. Where a thin plate is suspected the inspector drills through at that point to determine the exact thickness of the metal. If it is found all right he runs a tap through and screws in a plug, if thin, the whole plate is condemned and must be taken out and a new one put in its place. In the hands of a competent man the hammer test is a good means for determining the strength of the boiler.

30 *The Hydrostatic Test.* This is the test applied to most boilers to determine their strength, or the steam pressure they should be allowed to carry. In making the test, a reliable steam gage must be used. The boiler is first filled with water and then pressure is applied by a small hand force pump, care being taken to first open the pop valve so that no air may be compressed in the dome or upper part of the boiler. The pressure is then applied until the gage registers 50% more than the steam pressure the boiler is expected to carry. For example:—If the steam pressure is to be 100 pounds, the test should be carried to 150 pounds cold water pressure. During the test the inspector watches the gage, and if any sudden drop in pressure occurs it is evidence that a stay bolt or brace has given way. He also looks for leaks and for bulging of the boiler plates. If any weak plates are found they are marked and the inspector gives the necessary orders for repairs, at the same time he specifies the steam pressure which the boiler is permitted to carry.

31 *Testing The Boiler By the Expansion of Water.* Where a

force pump is not at hand the boiler may be given a water pressure test by taking advantage of the fact that water expands under the influence of heat.

32 In making this test the boiler is pumped full of water by means of the tank pump, taking care that no air is trapped in the steam dome. When the boiler is completely filled, a fire is built in the fire box. The heat causes the water to expand and put a pressure on the walls of the boiler. The same observations should be taken as during the pump test. If the boiler is completely filled with water, the pressure may be raised to almost any desired amount before the water reaches the boiling point. There is no danger of a boiler explosion in making the water test in either way, because water has no expansive force unless heated above the boiling point. Even if the boiler should burst, due to water pressure, it would simply crack open and allow the water to escape. However, if a considerable quantity of air were trapped in the upper portion of the boiler and then compressed, there might be, if the boiler should burst, a slight explosion, hence the necessity of getting rid of the air.

33 *Objections to the Cold Water Test.* Many engineers object to the cold water test on the grounds that it strains the boiler much more than steam, because the water pressure is carried so much higher than the steam pressure, and also because the metal is not quite so strong when cold as when warm. It is also claimed that a boiler may be injured during the test without the inspector knowing it. Like many other arguments there seems to be no clearly proven facts at hand by which to decide the case. The

objectors to the tests above described are not yet able to offer anything better and until they are able to do so, the cold water test will doubtless continue to be the standard method of testing.

- 34 *Boiler Explosions.* Whenever a boiler explodes it is due in most cases to the carelessness or the ignorance of either the man in attendance or of the boiler inspector. A boiler will explode when the internal pressure is greater than the strength of the metal in the boiler walls. This may come about through any of the following causes: First, poor material in the boiler; second, bad workmanship in building the boiler; third, a very high steam pressure, due to a faulty pop valve or a faulty steam gage; fourth, allowing water to get too low; fifth, a heavy coat of scale on those places exposed to the action of the fire, which allows them to become burned; sixth, carrying a higher steam pressure on an old boiler than it is capable of bearing. With the exception of the first two items all boiler explosions are, as stated before, due to either the ignorance or the carelessness of the man in charge. It is advisable in the case of old boilers to determine how much pressure they are able to stand by some method of testing, and then take care not to exceed that pressure. There are some men who boast that they are not afraid to run an old condemned boiler, but when they do so, they are simply advertising one of two things; either that they have no knowledge of the energy of steam, or else, that they have no common sense and do not know enough to be afraid. Since there seems to be considerable ignorance regarding the amount of energy in steam it may

not be out of place to present a few facts in this connection.

- 35 *The Energy of Steam.* There is an enormous amount of energy in steam and heated water in a boiler under pressure, much more than the average engineer realizes. Even after seeing the figures which represent this energy the mind is scarcely able to comprehend their meaning. The accompanying table which is taken from Thurston's "Manual of the Steam Boiler" shows the total available energy in one pound of water and of steam at different pressures.
- 36 Column I. represents the steam pressures. Column II. the corresponding temperature of the water and of the steam at the different pressures. Column III. shows the amount of energy expressed in foot pounds which is contained in one pound of water and which may be set free by explosion when the pressure falls to that of the atmosphere. Column IV. shows the amount of energy, in foot pounds, which one pound (by weight) of steam contains at the various pressures. Column V. shows the volume occupied by a pound weight of steam.
- 37 It will be observed on referring to columns III. and IV. that a pound of water contains much less energy than a pound of steam, but, since there are a great many more pounds of water than of steam in the boiler, it is evident that the whole mass of heated water contains much more energy than is contained in all of the steam. For example, at 100 pounds pressure, one pound of water contains 6885.2 foot pounds of energy, while a pound of steam at the same pressure contains 106672.8 foot pounds. The volume of the pound of water is a little more than one eighth of a

cubic foot, while the volume of a pound of steam at the given pressure is 4.33 cubic feet. In other words, at 100 pounds pressure, a pound of steam occupies about 34 times as much space as a pound of water; consequently, in the same amount of water space as that occupied by the steam, there will be much more energy in the water than in the steam; that is, volume for volume, heated water contains more energy than steam when both are at the same pressure and temperature.

38 In an ordinary 25 horse power traction engine boiler there are about 52 cubic feet of water and 26 cubic feet of steam. If the steam pressure be taken at 145 pounds gage pressure, the total amount of energy contained within the walls of the boiler can easily be computed by the aid of the table. By referring to a table showing the properties of steam it will be found that one cubic foot of steam at the given pressure weighs .35828 of a pound. In 26 cubic feet, therefore, there would be 9.32 pounds of water in the form of steam. Each pound of steam contains, at 145 pounds gage pressure, 132767.8 foot pounds of energy which may be set free by explosion. The total amount of energy contained in the steam must, therefore, equal 132767.8×9.32 or 1237385.9 foot pounds.

39 Referring to column III. the energy per pound of water at 145 pounds pressure is shown to be 11444.2 foot pounds. If the boiler contains 3250 pounds of water, the total energy in the form of heated water, will be represented by the product of 3250 and 11444.2 which equals 37193650 foot pounds. This sum, added to the energy in the steam, equals

TABLE I
Total Available Energy in Water and Steam. (From Thurston's Manual of the Steam Boiler.)

I Pressure above a vacuum in pounds per square inch	II Temperature in degrees Fah. of the steam and of the water from which it is evaporated.....	III Amount of energy in foot pounds contained in one pound of water, and which may be set free by explosion	IV Corresponding amount of energy in foot pounds contained in one pound of steam which may be set free by explosion and expansion to atmospheric pressure..	V Volume in cubic feet occupied by one pound of steam.....
20	227.9	145.9	15018.8	19.74
25	230.0	148.3	15282.4	18.00
30	232.1	150.7	15546.0	16.46
35	234.1	153.1	15809.6	15.10
40	236.1	155.5	16073.2	13.88
45	238.1	157.9	16336.8	12.77
50	240.2	160.3	16599.4	11.75
55	242.2	162.7	16862.0	10.81
60	244.2	165.1	17124.6	9.94
65	246.2	167.5	17387.2	9.14
70	248.2	169.9	17649.8	8.40
75	250.2	172.3	17912.4	7.71
80	252.2	174.7	18175.0	7.07
85	254.2	177.1	18437.6	6.48
90	256.2	179.5	18699.2	5.93
95	258.2	181.9	18961.8	5.42
100	260.2	184.3	19224.4	4.94
110	262.2	188.7	19750.0	4.33
120	264.2	193.1	20275.6	3.81
130	266.2	197.5	20801.2	3.36
140	268.2	201.9	21326.8	2.97
150	270.2	206.3	21852.4	2.63
160	272.2	210.7	22378.0	2.33
170	274.2	215.1	22903.6	2.06
180	276.2	219.5	23429.2	1.82
190	278.2	223.9	23954.8	1.60
200	280.2	228.3	24480.4	1.40
250	401.0	1734.4	157870.4	1.68

38431035.9 foot pounds of energy stored within the walls of the boiler in the form of both steam and water. The magnitude of such a force is not easily comprehended. In fact, the only way to gain an adequate idea of its immensity is to consider what it is capable of doing. For example, suppose it were so applied as to hurl the whole engine weighing 22830 pounds upwards into the air; how far would it go?

40 A little computation reveals the fact that it would reach an elevation of 1683 feet, or almost one-third of a mile, and that it would start with a velocity of 329.2 feet per second or something over 411 miles per hour.

41 *Road Management.* Handling a traction engine on the road is an art that can best be learned by practice. Some men become quite expert in a very short time and others never become really proficient. It is an art like driving team which comes handy to some and not to others. There are a few general directions, however, which may be given, that should prove helpful.

42 *Running with Governor Belt Off.* This is something that should never be done, especially when hauling a separator. What little time may be gained by a faster road speed is more than off-set by the wear and tear on the machinery.

43 *Handling the Throttle.* By the proper use of the throttle an engineer can make his engine move as slowly as he pleases or as fast as the governor will permit. It is the only means he has for controlling the speed of the engine in moving into position. Where a rather sharp turn is to be made the throttle should be closed until the engine just

moves. The turn can then be made easily and with certainty. The engineer can see just where he is going and has time enough to turn the steering wheel. An engineer should practice with the throttle until he can start the engine as slowly as he wishes. The ability to do this is absolutely necessary in order to back into the belt without throwing it off. It is also necessary to be a good hand at the throttle in order to back up to the separator, or to maneuver the engine in any place where the space to move in is limited.

44 Many engineers who are expert with the throttle do not use the friction clutch at all, but prefer to run with a "stiff gear."

45 *Drive Wheels in the Mud.* Care should be taken in going over low ground to keep away from the soft places. In fact, where the ground looks suspicious a man should always be sent ahead to select a safe road for the engine. In case the drive wheels do strike a soft place, the engine should run slowly and be kept moving unless the wheels begin to slip. Just as soon as this occurs the engine should be stopped or otherwise the grouters will dig out the earth from beneath the wheels and the engine will be stuck worse than ever.

46 The usual method of getting out of a mud hole and about the only ready means is to put planks, old rails, or brush in front of the drivers in order to give them a footing and then start the engine slowly. Where an engine is fitted with a winding drum a cable may be used to pull the engine out, as explained in Lesson VI. Sometimes the mud hooks may be used with good effect, or a long log chain fastened

to a solid anchor ahead of the engine, with the free end under the driver, may give sufficient footing to enable the engine to get on solid ground again.

47 In any event, if the engine is hauling a load when it gets in the mud, it should be uncoupled. After it gets on solid footing the load may be pulled through by means of a long chain, which, by the way, ought always to be carried for just such emergencies.

48 *Traveling over Loose Sand.* The secret of running an engine over soft, loose sand successfully is to go slowly. Do not try to pass over with a rush, but give the sand time to pack under the drivers. If the engine runs too fast the wheels will slip and the engine will bury itself without advancing. In case such an accident does occur the engine may be gotten out by the same methods employed in mud.

49 *Climbing Hills.* Before attempting a long hill be sure there is enough water in the boiler to last until the top is reached, and then get the steam pressure up almost to the popping off point.

50 It is never safe to attempt a hill on a low or a falling pressure. The engine is apt to get stalled before reaching the summit and a long stop will be necessitated in order to raise steam again. This is hard on the front ends of the flues which are not protected by water, and is apt to burn them badly.

51 When steam pressure is raised, start up the hill slowly so as not to agitate the water and cause priming. A good steam pressure and a slow steady gait is the best way to attempt a hard or long hill. If necessary, drop the reverse

lever down to the end of the reverse quadrant. The engine will then have its greatest power but it will also take a large amount of steam.

52 *Descending Hills.* In going down a steep hill the water flows to the front end of the boiler and the crown sheet is left bare. This condition of affairs makes it necessary to have very little fire on starting down a long steep grade, otherwise, the fusible plug will melt out and cause a good deal of trouble and delay. If the fire is heavy when the top of a very steep hill is reached it is better to draw it before starting down, and then rekindle it at the bottom.

53 *Crossing Bridges.* Many states have enacted bridge laws governing traction engines. These laws generally specify that the bridge must be planked with heavy planking laid lengthwise of the bridge, before the crossing is attempted. In states where such a law is on the statute books the engineer should be careful to comply exactly with its requirements. Otherwise, he will not, in case of accident, be able to collect damages. The object of the planking is to distribute the weight over as great a span of the bridge as possible. A moving load, like a traction engine, is much harder on a bridge than a dead load or one that does not provide its own motive force, for the reason that the structure must not only sustain the weight of the engine but also bear the reaction of the force which propels the machine.

54 It is a good plan to plank a bridge, if it appears at all weak, whether the law specifies that it be done or not. Unless the bridge is a good strong one it is better to un-

hook from the separator and take the engine over alone, then draw the separator across with teams or else with a long cable. Always move slowly in crossing a bridge. Unless the engineer is absolutely certain as to the strength of the bridge, he should, before attempting to cross, give it a thorough examination.

55 If a bridge has been condemned by the proper authorities and a notice posted on both ends of the bridge to that effect, the owner of a traction engine cannot recover damages if an accident occurs in crossing.

56 For traction engines of the larger size, bridges of not less than forty tons' capacity should be constructed. Owners of such rigs would do well to use their influence to have bridges of the proper strength constructed in their respective townships.

57 The following table shows the average weights of traction engines and separators, of different sizes, and may be used as a guide in determining the strength of bridge to build.

Table II.

Approximate Weights of Traction Engines and Separators.

HORSE POWER OF ENGINES.	WEIGHT OF ENGINE IN POUNDS.	SIZE OF SEPARATOR.	WEIGHT OF SEPARATOR.
12	12000	36-54	5000
16	16000	36-58	6000
18	18000	40-62	6000-7000
20	15700-20000	44-66	7000-9500
22	16000-22000	44-72	8000-9500
25	17000-23000		
30	21000-28000		
35	28000-30000		
Plowing Engines	28000-36000		

58 *Lining up to the Separator.* After the separator is pulled into place the engine may be brought into line by making a wide circle either to the right or to the left, or else, it may be run forward a short distance, turned either to right or the left until it stands at right angles to the separator, and then reversed and backed into position. The drive belt should be pulled out in line with the separator. This will aid the engineer considerably in making correct alignment. If there is little or no wind, or if the wind blows lengthwise of the belt, the outside edges of the driving pulley on the engine, and the cylinder pulley on the separator, should be in the same straight line as shown in figure 147. If the wind blows from either side very hard the engine should be set slightly out of line, see figure 148. The action of the wind will move the belt sidewise and the engine must be

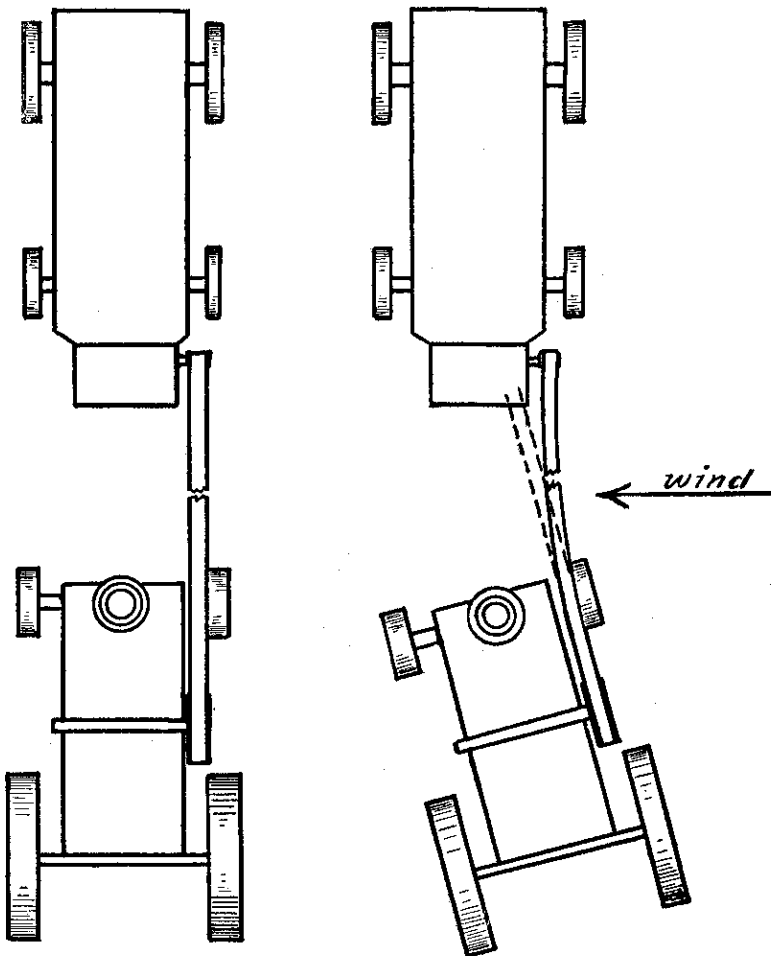


Fig. 147. Lining to Separator. Fig. 148.

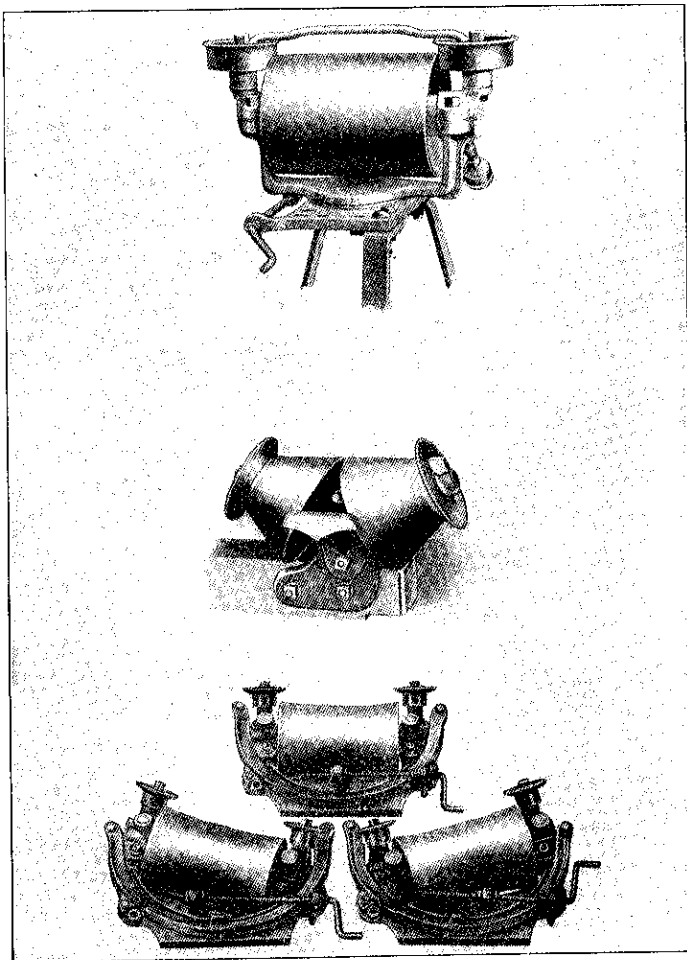
set over to off-set its effect an amount sufficient to cause the belt to run straight upon the driven pulley. It does not matter much at what angle a belt leaves a pulley provided it runs on straight. If it does not run on straight it will have a tendency to run off to one side or the other.

59 It is rather difficult to judge just exactly how much off-set to make for the action of the wind, and so numerous belt guides have been devised which are supposed to take care of the belt in ordinary side winds. A few of the more successful of these are illustrated in figure 149.

60 In lining up to a separator quickly the engineer must exercise good judgment and determine at a glance just where the engine should stand and how he is going to get it there before starting. If he runs slowly when he gets almost to position he can line up correctly without much difficulty.

61 *Putting on the Drive Belt.* To do this the engine is run forward far enough so that the belt can be slipped on easily, then reversed and backed into place. Or, the belt may be put on while the fly wheel is in motion either by hand or with a "belter," which is a device made especially for this purpose. If put on by hand, the belt should be pressed against that side of the wheel which at the given instant is moving away from the direction of the belt. After the belt is in place the engine should be backed slowly until it is given the proper tension.

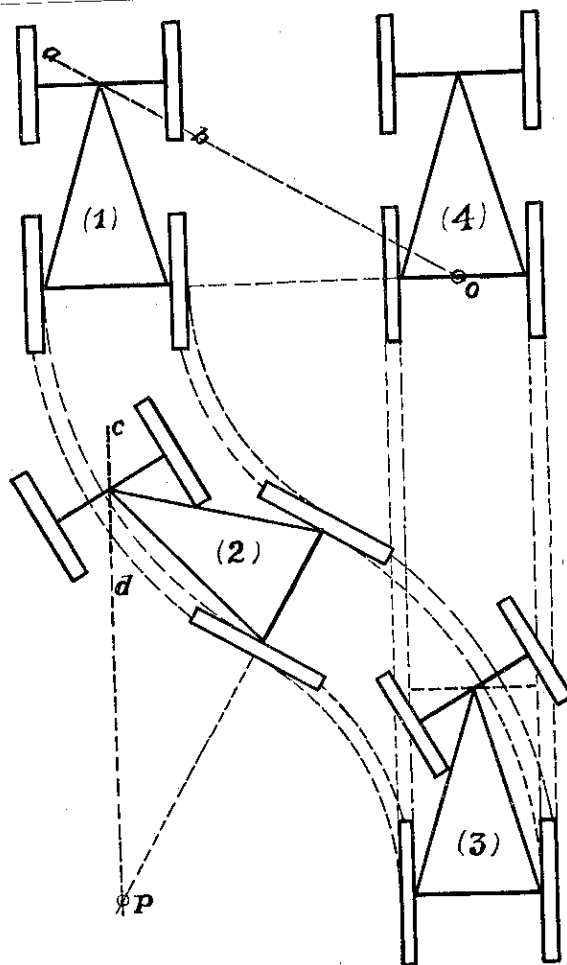
62 A great many engineers make the mistake of running with the drive belt too tight. A rubber belt 160 feet long is very heavy and in order to pull it up where it shows very little sag in the middle the tension must be excessively great.



Belt Guides. Fig. 149.

This causes a very heavy load on both the separator boxes and the engine bearings and is, perhaps, the most fruitful cause of trouble through hot boxes at these points. The belt should be pulled up until it clears the ground and has some little tension, but not so tightly that it does not sag a considerable amount in the center.

- 63 *Blocking the Engine.* Double cylinder engines are very well balanced and do not need to be blocked in order to hold them in place unless the ground is very hard. Single cylinder engines or tandem compound engines, however, frequently require blocking. This may be accomplished by using a heavy block in front of one of the drive wheels, or with a short plank, one end of which is shoved under one of the drivers and the other held up by means of a jack screw. Sometimes digging a shallow hole in the ground is all that is necessary.
- 64 *Moving the Engine a Short Distance to the Right or Left.* Young engineers, especially, seem to have a good deal of difficulty in moving an engine sidewise a short distance, so it would seem, at least, judging from the awkward attempts that a good many of them make.
- 65 There are two ways in which this may be accomplished; first, by backing up and then running forward into position as shown in fig. 150, or else, by reverse process, in which the engine is first run forward and then backed to place.
- 66 Referring to the diagram, suppose it is desired to move from position 1 to position 4. The first thing to do is to cramp the front wheels to the position shown in a b. When the engine is backed it swings about the centre O. Then,



Moving an Engine Sidewise. Fig. 150.

when position 2 is reached, the front wheels are cramped to the position c d, thus causing the engine, when it is backed further, to turn about a centre at P. When position 3 is reached the front wheels are straightened into line with the new position 4, and the engine is run forward to the desired place.

67. A little study of this diagram ought to make it easy for a student to make a similar sketch showing how the engine may be run forward and then backed into position, moving a short distance sidewise at the same time.
68. *Engineer's License Laws.* Nearly all of the states in the Union require all engineers to pass an examination before being granted a license to run a steam engine.
69. In states where such a law has been enacted, a man who runs such steam machinery without first receiving a license or permit is deemed guilty of a misdemeanor and is subject to a heavy fine. These licenses are granted by an inspector appointed by the proper state authorities. In case the applicant does not know where to apply he can obtain the required information by addressing the Sec'y of State, or Chief Boiler Inspector at the state capitol.
70. *Classes of Engineers.* Engineers are divided into classes depending upon their experience and previous training, such as chief engineer, first class engineer, second class engineer, or special engineer; the qualifications differing for each class.
71. In every case the applicant must be of proper age, usually twenty-one or over, and be of good character. A chief engineer is granted license to run any size of engine or

handle steam machinery of any capacity. Those of lower grade are limited in regard to the power of engines they are allowed to operate.

- 72 All engineers, except those holding special licenses or permits, must have had a certain amount of practical experience specified by law. Special engineers merely have to satisfy the inspector or examining board that they are sufficiently acquainted with steam machinery to be safely entrusted with its care and operation. Since the laws differ somewhat in different states or in different countries, no definite instructions can be given in regard to engineer's license laws. The proper thing to do is for the applicant to find out from the proper authorities what the laws are in his state or province and then study to meet these requirements. A license can be revoked by the authorities which granted it on proof of incompetency of the licensee.
- 73 *Laying up an Engine.* Unless an engine is properly cared for during the time it is standing idle it may deteriorate almost as much as while working. Traction engines are well made. Good material is used throughout and skilled labor is employed in manufacturing. With proper care they should last for a long term of years, considering the fact that they are in operation only a small portion of each year. As a matter of fact, their average life is short, due to the ill usage they receive in the field and especially while lying idle. A traction engine costs a large sum of money and if the owner wishes to make a profit on his investment it must be taken care of.
- 74 At the end of the season, the boiler should be drained and

thoroughly cleaned. All scale and mud should be removed and the boiler then filled with cold water. Two or three gallons of a good heavy *mineral oil* should be poured in on top of the water. Then when the bottom blow off is opened the oil settles on the sides and helps keep the inside from rusting.

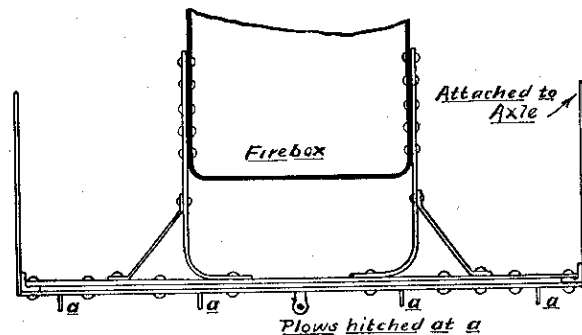
- 75 The ash pit and the combustion chamber should both be cleaned thoroughly. Ashes or soot collect moisture and this causes iron to rust.
- 76 *Care of Engine Parts, Pumps, Etc.* The independent pump should be removed from the engine, taken apart, dried, and put away in a dry place. Unless this is done it will require a liberal dosing of kerosene to remove the rust in order to start the next season.
- 77 The packing should be removed from the piston rod stuffing box and the inside of the cylinder given a coat of oil. This is accomplished sometimes by flooding the cylinder with oil the last time it runs, and sometimes by taking out the piston and giving it a coating of hard oil.
- 78 All bright iron or steel parts should be given a coating of a preparation made by melting equal parts of tallow and white lead together. The smoke box and chimney can be protected by painting them with asphaltum paint.
- 79 *Housing the Engines.* An engine should be kept in a clean, dry place. No man can afford to own a traction engine unless he also has a house to keep it in. A shed is all right provided it is rain tight and has a dry floor. With proper care and proper housing any kind of machinery can be made to last very much longer.

- 80 *Painting Machinery.* There is no better preservation for either wood or iron than paint. As stated before in these lessons, rusting is due to moisture in the presence of air acting upon iron. If the moisture and air can be excluded the iron will not rust and this is easily accomplished by a judicious use of paint.
- 81 The rotting of timber is almost an identical process with the rusting of iron and can be prevented by keeping the wood enclosed in a coating of paint. It would pay every thresherman at the *end of the season* to clean and paint all such parts about both the engine and separator from which the paint has been scraped during the working season.
- 82 *Plowing with a Traction Engine* was first taken up in England some forty or fifty years ago, and not only proven practical but was put upon a satisfactory working basis before it was introduced in America. In the U. S. the first steam plowing outfits were put on the market about twenty-five years ago, but were not looked upon with general favor until within the past eight or ten years, when the development of the large farms in the West, and the scarcity of labor, brought them into prominence.
- 83 At the present time, 1907, steam plowing is one of the most important uses, next to threshing, to which the traction engine is adapted.
- 84 *Size of Engine for Plowing.* The expense of running a small sized engine in plowing is almost as great as running a large one, consequently, rigs of twenty-five rated horse power and upwards are in most general use. The actual power of these engines, of course, ranges much higher.

- Many of the most successful outfits operating in the West range anywhere from fifty to 120 actual brake horse power, and will develop this amount of power for hours at a stretch. It is generally conceded that it does not pay to plow with an engine rated under twenty-five horse power.
- 85 *Peculiarities in the Design of Plowing and Grading Engines.* The parts most liable to wear and break in plowing engines are the driving gears and the countershaft. Consequently, these parts are made much heavier and stronger than for ordinary threshing, the bearings are made longer, and those parts of the boiler which are liable to spring are made stiffer. The adaption of the traction engine to plowing has perhaps been the principal factor in their recent development.
- 86 *Methods of Hitching Plows to Engine.* There are two distinct methods of hitching plows to a traction engine. Ordinary gangs may be attached by means of chains to a beam extending across the rear of the engine. Or a solid frame may be used, which supports the plow bottoms. In the first method, the beam is sometimes attached to the rear axle by means of radius links, and sometimes by heavy iron or steel straps, riveted to the sides of the fire box (see fig. 151). With radius links the beam can move up or down a certain amount and thus accommodate itself, to a certain extent, to the inequalities of the ground. Where a rigid beam is used, the chains are depended upon to furnish the up and down movement.
- 87 In the second method, a separate frame is provided, which is made in various sizes to accommodate as many plow

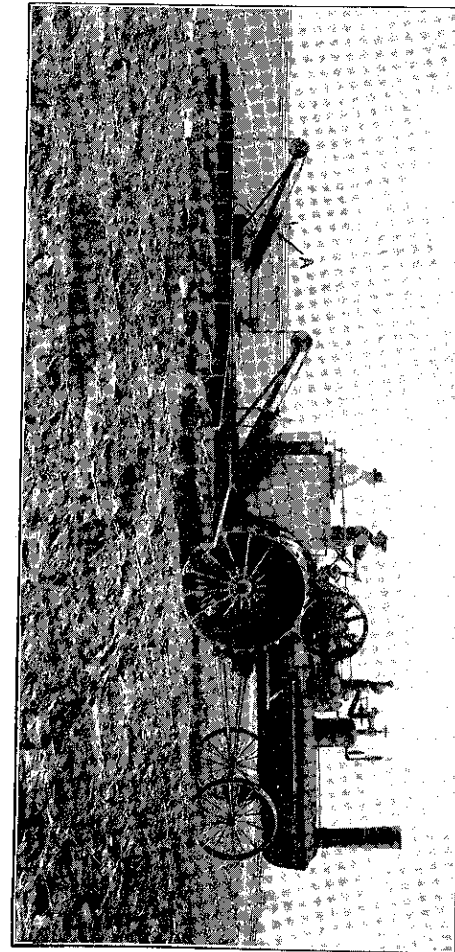
bottoms as the purchaser may desire. These plow frames are made in quite a variety of styles. In some, each plow is made independent, while in others the plows are arranged in gangs of three or four, each section being independent of its neighbors, and arranged to be raised or lowered either by hand levers or by steam.

- 88 *Plow Frames for Traction Engines.* Fig 152 illustrates a type of frame in which each plow is made independent. A distance bar holds each plow bottom from its neighbor, hinged in such a way that it is free to move up or down,



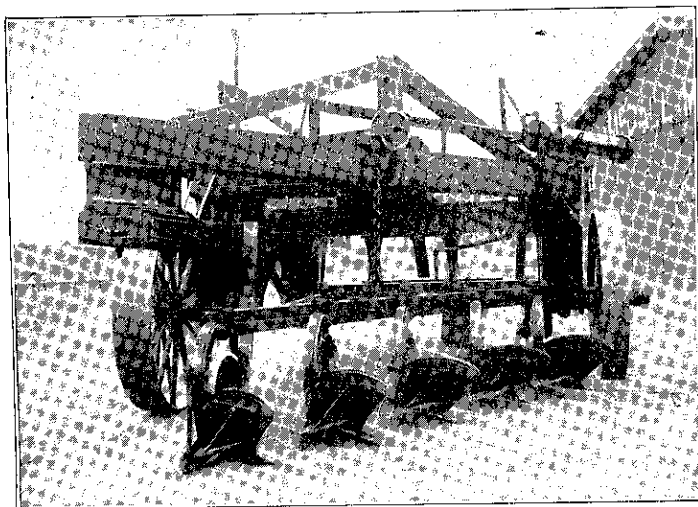
Plow Beam Bolted to Firebox Sides. Fig. 151.

but not sidewise. Each plow beam is attached to the frame by means of a wooden plug, which is designed to shear off and let the plow drop out of the frame should it chance to meet a serious obstacle. The lifting of the plows is accomplished by means of a chain passing over a pulley and attached by means of a piston rod to a piston operated by



Plow Frame, Fig. 152.
Plows Independent.

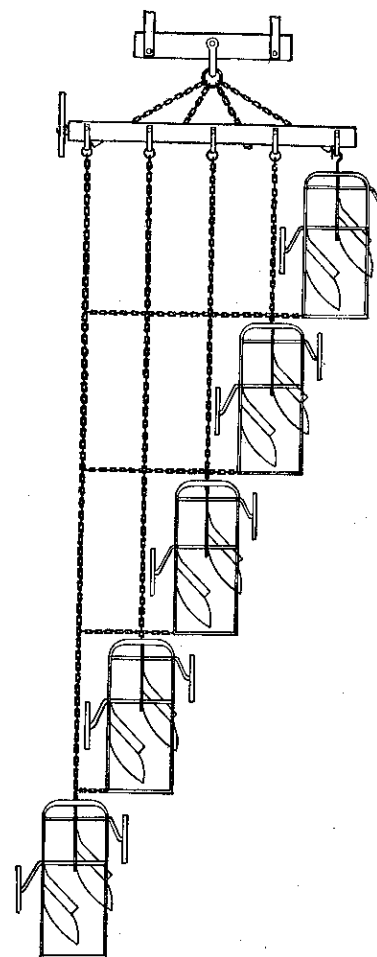
steam from the traction boiler. See A in the figure. When steam is released from the cylinder by means of a valve on the engineer's platform, the weight of the plows pulls the piston back. The depth of furrows is regulated by



Plow Frame, Plows Held Rigidly Together in Gangs. Fig. 153.

hand levers on the plow frame, all of which is plainly shown in the illustration.

- 89 In Fig. 153 the plows are suspended from a high frame as shown, and are rigidly fastened together in gangs. Arranged this way they cannot meet the inequalities in the ground as well as shown in Fig. 152, but possess another advantage of perhaps equal merit in that they are not



Arrangement of Chain Web or Rods for Steam Plowing. Fig. 154.

thrown out of the ground as easily when it is hard and baked. A steam cylinder is also provided, which enables the operator to lift one or more of the sections out of the ground. In both styles, a lock is provided to hold the plows up after they have been lifted by the piston.

90 *Advantages of the Plow Frames.* The principal advantages obtained in the use of the plow frames may be summed up about as follows:

1. The whole outfit is compact, strong, and ready to hitch onto in a moment's notice.

2. They can be used to advantage in a smaller field than where ordinary gangs are used.

3. The plows can be lifted out of the ground instantly, and backed or turned as desired, thus saving time, and making it possible to plow the corners of the land.

91 *The Use of Ordinary Gangs.* Fig. 154 shows how a number of ordinary gang plows may be attached to a traction engine by chains or rods. A great many thousand acres have been plowed in this way and while the arrangement is not wholly satisfactory in turning the headlands, it has the great advantage of cheapness. For small fields this arrangement is not as handy as the plow frames.

92 *Keeping Accounts.* Operating a traction engine and threshing outfit in doing any kind of work, is a business of considerable magnitude, involving, as it does, the expenditure of \$3000 or \$5000. In order to be successful, it must be managed just as any other business enterprise is managed. In other words, a careful system of accounts must be kept and all items taken into consideration, such as first

cost, interest, depreciation, labor, fuel and oil, tools, incidentals, etc. Unless such an account is kept, the owner cannot tell whether he is making money or not. The proper thing to do, therefore, is to keep a simple set of books, and keep exact account of everything. In this way it will be possible to determine at any time if the investment is paying, or if it is not, the books ought to show what the trouble is, and suggest a remedy.

93 *How to Figure Cost of Steam Plowing.* No very authentic information has yet been gathered on this subject. Men who operate plowing outfits even in the same locality do not agree on the cost of operating such rigs. This is due to the fact that they do not keep a strict account of receipts and expenditures. Many estimates have been made, but even these do not agree.

94 The items to be considered are: Total cost of labor, interest on the investment, wear and tear on the outfit, cost of repairs, cost of fuel, cost of oil and incidentals. If the total expense be divided by the total number of acres plowed, the quotient will be the cost of plowing one acre.

95 The number of men employed ranges from three to four, according to local conditions. One to run the engine, one to look after the plows and act as fireman, one to haul water, and one to haul fuel. At least one, and often two teams are necessary, depending on the fuel used and the distance it must be hauled. The amount of coal burned varies with the character of the soil, the condition of the engine, the skill in firing, and the quality of the coal. In stubble plowing where the ground is mellow and a good grade of soft

coal is used, the coal consumption is about 100 pounds per acre. The cost of labor depends upon local conditions entirely. The cost of repairs is also not easily estimated. A number of users place this item at one cent per acre, but the estimate is undoubtedly far too low if figured on the whole life of the engine, because, as the engine grows older, the repair bills become necessarily much heavier. The deterioration charge, or charge on wear and tear of the engine is hard to estimate. This charge is usually rather high. Often the deterioration while the engine is standing idle is almost as great as while running. This is the case if it is not thoroughly cleaned and properly housed. The best that can be done is to make an estimate of how many years the engine will last, and then estimate the number of actual days it will run in each year. Multiply these two items together and the product will be the total number of day's work the engine will do. Now divide the total cost by the number of days so estimated, and call this quotient the fixed daily charge for deterioration. This will be a fair estimate, because even though deterioration occurs while standing idle, it can only be made up while the engine is at work. The interest on the investment must always be figured on the prevailing rates of interest in the locality where the engine is used. This charge is say 8% per year. On \$2500 it would be \$200 per year. It should, however, be charged against the actual number of days the engine runs. If this is 40 days per year, the interest per day is \$5.00. This method of charging interest is fair because the engine can only be made to pay when it is actually at work. To find

the actual cost of plowing one acre, add the cost of labor, cost of repairs, cost of fuel, cost of oil and incidentals, interest charge, and deterioration charge, as computed for one day in each case, and divide this sum by the total average number of acres plowed per day. To make a profit on the investment it will be necessary to charge considerably more than the actual cost. The amount to be added for profit can be figured on the total investment just as interest is figured.

QUESTIONS.

1. Explain how an engine is unloaded from the cars.
2. What precautions should be taken with a new engine?
3. What precautions should be taken with a new boiler, in regard to water and raising of steam?
4. How is steam pressure regulated?
5. What are the fireman's duties in the morning?
6. What are the fireman's duties at night?
7. Explain how to clean a fire?
8. What tools should an engineer provide himself with?
9. What extras should be carried in the tool box?
10. State three methods of testing a boiler, and explain each method?
11. What causes a boiler to explode?
12. How many foot pounds of energy are there in one pound of steam at 100 lbs. pressure? In one pound of water at 100 lbs. pressure?

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13. How is the road speed of a traction engine regulated?
14. Explain how to get out of a mud hole with a traction engine?
15. What precautions should be observed in climbing hills?
16. What precautions should be taken in crossing bridges?
17. Show, by a diagram, the effect of a side wind on the belt when running a separator?
18. Explain, by a diagram, similar to figure 150, how to move an engine a short distance sidewise, by first running forward?
19. What should be observed in laying up an engine at the end of the season?
20. Of what use is paint in preserving machinery?
21. How are plows attached to a traction engine?
22. Explain the advantages and disadvantages of plow frames over ordinary gangs?

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LESSON WITH QUESTIONS

THE STEAM ENGINE
PART VIII

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

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TO SECURE the best results from your work in the Clarke School of Traction Engineering by Correspondence we suggest the following:

1. Study only a portion of a lesson at a time.
2. Be sure you understand each illustration before passing to another.
3. Before answering the questions carefully review the entire subject.
4. In answering do not write the questions—merely use their numbers.
5. Answers **MUST** be written on good white paper, in ink, and only on one side of the sheet.
6. To avoid mistakes and in order that you may receive proper credit for your work, always write your name, your address and the number of the lesson at the top of your first answer sheet.
7. After writing your answers neatly fold the sheets and enclose in an envelope to us, writing your name and address in the upper left hand corner of the envelope.
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LESSON VIII.

THE STEAM ENGINE.

- 1 *Definition.* A steam engine is a machine which changes the heat energy of steam into work. These machines are made in a variety of ways and fall naturally into several classes.
- 2 *Classification of Steam Engines.* They may be classified according to the service for which they are designed, according to the number and position of the cylinders; according to the valve motion; or according to the motion of the piston. In the first group we have: stationary, portable, marine, locomotive and traction engines.
In the second group: simple, compound, triple expansion, quadruple expansion and double cylinder simple engines.
In the third group: reciprocating engines, rotary engines and steam turbines.
Reciprocating engines may be either single or double acting, that is, take steam at one end or at both ends of the cylinder. They may also be made with the cylinder vertical or horizontal or inclined.
- 3 *How an Engine Runs.* It is a mystery to many people, especially boys, how a light gas-like substance like steam can have power to run a heavy machine. Fig. 155 is a diagram intended to illustrate this point and to show how reciprocating motion, that is, back and forth motion, is changed to rotary motion.

Suppose pipes, A and B, were connected to a boiler under

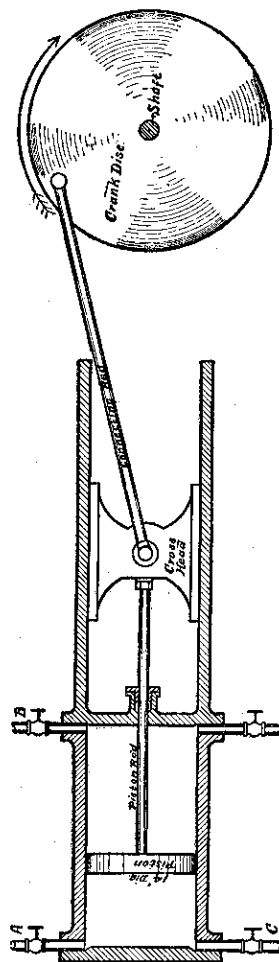


Diagram Showing How Reciprocating Motion is Changed to Rotary Motion. Fig. 155.

THE STEAM ENGINE.

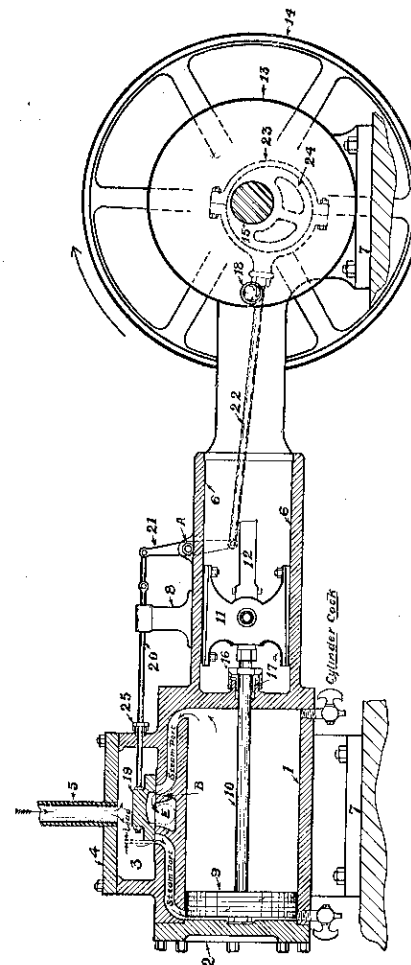
a steam pressure of 100 lbs. per square inch, and furthermore let us suppose that the piston is 14 inches in diameter and that it works back and forth in a steam tight cylinder. The area of this piston, therefore, is $14 \times 14 \times .7854$ or almost exactly 154 square inches. If valve A were opened, with the piston in the position shown, steam would flow in on the left hand side of the piston and exert a pressure almost equal to boiler pressure. Since this is 100 lbs. per square inch and the piston has an area of 154 square inches, the total pressure on the piston must be 100×154 or 15400 pounds. This force causes the piston to move towards the right and do work. Motion is transmitted through the piston rod and the connecting rod to the main shaft and causes the latter to rotate. If, when the piston reaches the end of its travel toward the right, valve A were closed and valves B and C opened at the right instant, the crank would keep on turning in the direction of the arrow and the piston would start back toward the left. The object of opening C is to let steam behind the piston escape; thus the back and forth motion of the piston is changed, by means of the cross head, connecting rod and crank, into rotary motion at the main shaft. Of course, with the arrangement shown in the diagram, the engine would very likely stop on dead centre, and would need the addition of a heavy fly wheel to keep the piston from stopping at the end of its stroke in either direction. Such an arrangement of pipes and valves would also be impracticable in a working engine, and so some sort of automatic valve must be provided which will let steam in behind the piston at the

right instant and let it escape from the opposite side when the piston starts on its return stroke.

- 4 *Classification of Farm Engines.* All farm engines are of the reciprocating type and may be divided into the following classes: Simple engines, double cylinder or duplex engines, tandem compound, and cross compound engines.
- 5 A simple engine has only one cylinder and has the minimum number of parts. A duplex engine has two cylinders each of the same size. Both are connected to the same shaft, but otherwise are entirely independent of each other and are, in fact, two separate simple engines.
- 6 Tandem compound engines have two cylinders, one large the other small, placed end to end. Steam enters the small cylinder first and then exhausts into a chamber which supplies the large or low pressure cylinder. Both pistons are fastened to the same piston rod.
- 7 Cross compound engines are provided with two cylinders, one small, the other large, placed side by side and connected up to the same shaft by cranks placed at right angles. Steam first enters the small cylinder and then exhausts into a chamber called a *receiver*, from which it is drawn to supply the low pressure cylinder.

All of these different classes of engines are in common use at the present time, and any of them will give satisfaction when handled right.

- 8 *Construction of a Simple Engine.* Fig. 156 represents a sectional view of a simple engine, taken lengthwise through the centre of the cylinder. In the majority of engines the steam chest is placed directly back of the cylinder, thus



Sectional View of a Simple Engine. Fig. 156.

making a straight connection from the eccentric to the valve. In order, however, to show the construction better, the steam chest is placed on top of the cylinder in the drawing, thus making it necessary to put in a *rocker shaft* between the eccentric and valve. This plan, while not used on traction engines, is perfectly feasible and is sometimes, though not often, adopted in stationary practice.

- 9 Referring now to the numerals shown in the diagram in Fig. 156, 1 represents the cylinder; 2, the cylinder head; 3, the steam chest in which the valve moves; 4, the steam chest cover; 5, the steam pipe which supplies the engine with steam from the boiler; 6, the guides, and 7, the engine bed or frame. In an engine of this class the cylinder guides and frame are cast in one piece. 8, is the guide for the valve stem. The parts just named constitute the *fixed* or *stationary* parts of the engine.

No. 9 represents the piston; 10, the piston rod; 11, the cross head; and 12, the connecting rod, only part of which is shown in the figure. 13, is the crank disc, and 14 the fly wheel, which is keyed to the far end of the main shaft, 15. 16 and 17 represent the piston rod, stuffing box, nut and gland; and 18, the crank pin to which the other end of the connecting rod is attached. The numbers from 9 to 18 inclusive, designate the *movable parts* of the engine.

The valve which, by the way, is a plain D slide valve, is shown at 19. 20 represents the valve stem; 21, the rocker arm pivoted at A; 22, the eccentric rod; 23, the eccentric strap, and 24 the eccentric sheave. The eccentric sheave and strap are behind the disc and so are shown in dotted

lines. The valve stem stuffing box is shown at 25. The valve and eccentric together with all connections constitute what is called the *valve gear*.

- 10 Steam first flows into the steam chest and from there is admitted by means of a valve, first into one end of the cylinder, then into the other. With all of the parts in the position shown in the diagram, steam will flow in the direction of the arrows, from the steam chest past the left edge of the valve and into the left end of the cylinder. At the same time, the steam on the right-hand side of the piston, left from the preceding stroke, is permitted to escape through the right hand steam port and through the hollow part of the valve, over the bridge B, to the exhaust pipe E, from which it escapes to the atmosphere, in all *non-condensing* engines; or into a condenser, if the engine is a *condensing* engine.

All traction engines are non-condensing engines.

- 11 *Definitions.* The end of the cylinder farthest from the main shaft is called the *head end* and the end nearest the crank, the *crank end* of the cylinder. A traction engine when running in the belt is said to be running *over*, when running in the opposite direction it is said to be running *under*. In stationary practice an engine is said to run *over* when the top of the fly wheel moves away from the cylinder and to run *under* when the top of the fly wheel runs in the opposite direction.

- 12 *Clearance.* The space between the piston and the cylinder heads when the piston is at the end of its stroke is usually spoken of as clearance. Strictly speaking, clear-

ance also includes the volume of the steam ports in addition to the space above mentioned. The distance between the piston and the cylinder head when the piston is at the end of its stroke, is, in traction engines, not to exceed $\frac{1}{2}$ an inch, and often much less. Whenever the piston is removed it is necessary to screw the piston rod into the cross head far enough to equalize the clearance at both ends of the cylinder.

- 13 *Directions for Equalizing Clearance.* The length of the cylinder, between the heads, must be equal to the length of the stroke plus the thickness of the piston plus twice the clearance space. If the piston is out of the cylinder it is easy to measure the length of the cylinder, the thickness of the piston, and to find the length of the stroke by measuring the crank. From these dimensions the clearance space can easily be found.

- 14 *Example.* Suppose the length of the cylinder is $14\frac{7}{8}$ inches, between heads; length of stroke 12 inches; thickness of piston $2\frac{1}{2}$ inches; how much clearance space must be allowed at each end?

- 15 *Solution.* 12 plus $2\frac{1}{2} = 14\frac{1}{2}$ inches occupied by the piston and the stroke. The remaining distance in the cylinder belongs to the clearance. $14\frac{7}{8}$ minus $14\frac{1}{2} = \frac{3}{8}$ of an inch. Half of this amount, or $\frac{3}{16}$ of an inch, is the amount of the clearance at each end. If the crank is placed on the head end centre, and the piston rod screwed into the cross head until it shows $\frac{3}{16}$ of an inch of clearance, it will be adjusted at the other end also, for the example just given.

- 16 The clearance may also be adjusted without taking the cylinder heads out in the following manner. The occasion for doing this arises when the cross head has to be removed for repairs and it is not deemed necessary to take out the piston. First, connect up the cross head, connecting rod and piston; then turn the crank to its extreme position to the right. This will pull the piston to the crank end of the cylinder. Now make a mark across the cross head and guides and disconnect the connecting rod from the crank pin; then, by means of a crow bar or heavy rod, push the piston as far toward the crank end of the cylinder as it will go. The distance between the mark made on the guides and the one on the cross head will be the clearance at the crank end of the cylinder.

If the piston is now pushed back to the head end of the cylinder by means of the crank pin resting against the inner brass on the connecting rod, it will stop when it reaches the end of its travel in that direction. By again marking the cross head and guides, and then pushing the piston as far as it will go toward the head end of the cylinder, the distance between the marks will as before indicate the clearance at the head end. If there is any difference in the clearance between the head end and the crank end, correction may be made by screwing the piston rod either into or out of the cross head an amount equal to *half* of this difference.

- 17 The clearance space should be equal for several reasons; the engine works better and takes less steam, and there is less danger of water in the cylinder causing damage to

the cylinder head if there is space enough for it to collect in.

- 18 Water, by the way, is incompressible and if more gathers ahead of the piston than enough to fill the clearance space it may cause a cylinder head to be broken. Whenever an engineer hears the groaning noise made by water in the cylinder he should open the cylinder cocks.

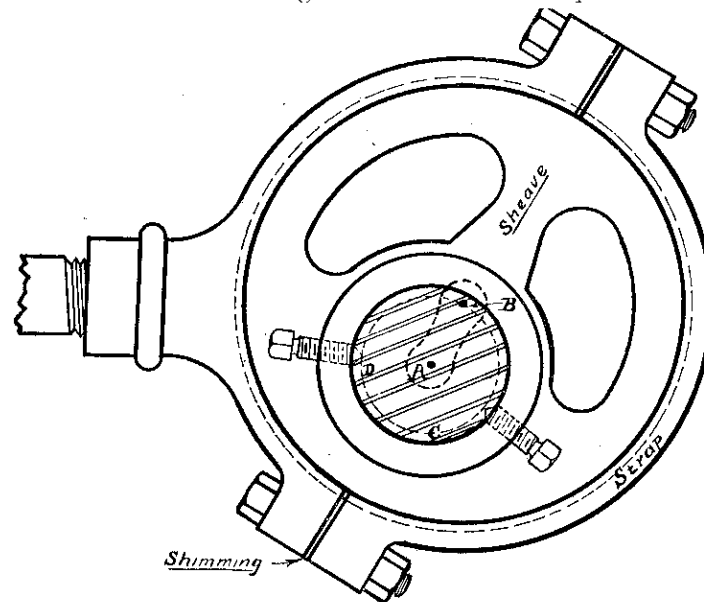
- 19 *The Size of an Engine* may be designated by stating its rated horse power, or, what is better, stating the size of the cylinders in inches. Where this plan is adopted the diameter in inches is named first and then the length of the stroke. A 7 x 12 engine would mean one having a cylinder seven inches in diameter and a stroke 12 inches long.

In the case of a compound engine, the diameter of both cylinders is expressed first, followed by the length of the stroke, all expressed in inches. For example, an engine 7 x 12 x 14 means that the small cylinder is seven inches in diameter, the large one twelve inches, and that both have a fourteen inch stroke.

- 20 *The Eccentric.* Motion is given to the valve by means of an eccentric, which is secured to the main shaft. An eccentric acts just like a crank. In fact it is a crank enclosed by a circular piece of metal, revolving inside of a strap to which the eccentric rod is attached. The meaning of the word "eccentric" is off centre. An eccentric, therefore, is a wheel that is off centre.

A line drawing of an eccentric is shown in Fig. 157. The centre of the shaft is at A, and the centre of the eccentric at B. The eccentric sheave is secured to the main shaft

by means of set screws, consequently, when the shaft revolves, the point B moves in a circle whose radius is AB. Since the eccentric sheave revolves within the strap, the latter must move to the right or left a distance equal to AB.



The Eccentric. Fig. 157.

The distance AB is called the *throw of the eccentric* or sometimes the *eccentricity*. The use of an eccentric on all steam engines is to give motion to the valve. It is secured to the main shaft sometimes by means of a key, but generally by means of set screws. The correct motion of

the valve depends largely upon the position of the eccentric relative to the crank. A discussion of this subject will appear in the following pages.

- 21 *The Slide Valve* is a valve working back and forth in the steam chest of an engine, and admits steam, first into one end of the cylinder, then into the other. At the same time it allows the steam which has been used in the preceding stroke to go out through the exhaust pipe. A plain D slide valve is shown in figure 162. The metal upon which the valve slides is called the *valve seat*. The passages from the steam chest to either end of the cylinder are called the *steam ports*. The steam which the valve admits to the cylinder up to the point of cut off, is called *live steam*. Steam that passes out of the exhaust pipe is called *exhaust steam*. There are quite a good many different styles of valves, a number of which will be described in Lesson IX.

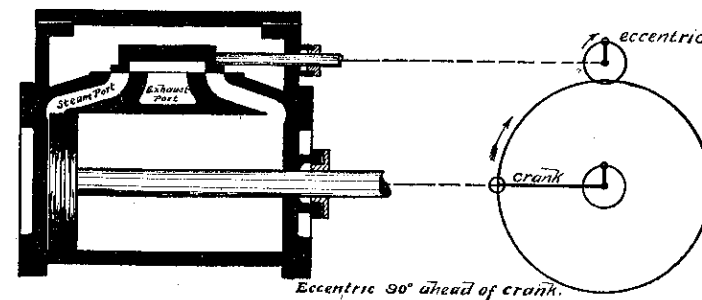
- 22 *A Square D Valve.* Fig. 158 is a diagrammatic view of a plain slide valve engine fitted with a "square" D valve. A "square" D valve when in its central position will just exactly cover both steam ports without overlapping the ports on either the inside or the outside edge.

The eccentric is always secured to the main shaft, and the steam chest is located generally on the side of the cylinder. Such an arrangement can not very well be illustrated and so, in the diagram, the steam chest is shown above the cylinder and the eccentric above the main shaft and in line with the steam chest. The position of the eccentric relative to the crank is shown correctly in all cases. Instead

THE STEAM ENGINE.

of showing the eccentric sheave and strap, it is represented by a small crank, which is also again indicated at the centre of the main crank circle where it more clearly illustrates the relative positions of crank and eccentric.

- 23 *Steam Distribution with a Square Valve.* Referring again to Fig. 158, the valve is exactly in the middle of its travel to the right or left; consequently the eccentric must also be in the middle of its travel, and therefore in a vertical position. If the fly wheel is to turn in the direction of the arrow, it is evident that the eccentric must occupy the position shown in Fig. 158, for then any movement of



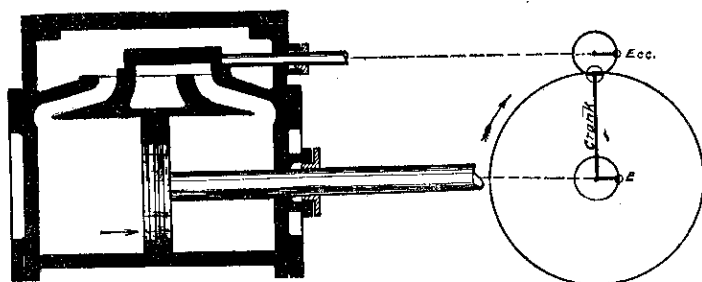
Square Valve in Mid Position. Fig. 158.

the main shaft in the direction indicated will cause the eccentric to pull the valve toward the right and open the left hand port, thus letting steam in on the left side of the piston and causing rotation to take place in the direction of the arrow.

- 24 With a square valve the eccentric must be placed just

a *quarter of a turn* or 90 degrees from the crank, as indicated in the figure. If no rocker shaft intervenes between the eccentric and valve like the one shown in Fig. 156, then the eccentric must be 90 degrees *ahead* of the crank. In an engine like the one described on page 352, the crank follows the eccentric. We will now investigate the action of the valve, piston, and eccentric during a complete revolution of the fly wheel. If this, the simplest possible arrangement, is first thoroughly mastered, the more complicated movements can be readily understood when they are presented.

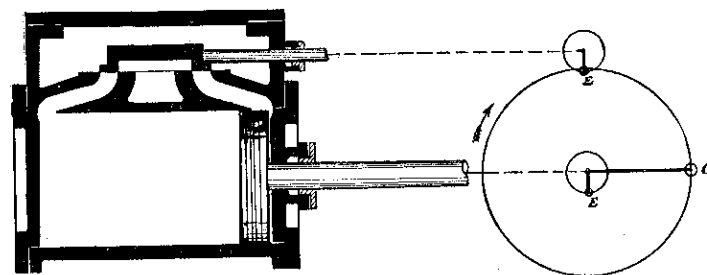
- 25 In Fig. 158 the piston is at the end of its stroke and the valve exactly covers both ports. Any movement of the



Square Valve, Left Steam Port and Right Exhaust Port Wide Open. Fig. 159.

crank upward will move the valve toward the right and admit steam to the left side of the piston; at the same time any steam on the right side of the piston can escape through the right hand steam port, over the bridge, and through

the hollow part of the valve to the exhaust pipe. As the fly wheel revolves the valve will continue to open until the eccentric reaches its extreme travel towards the right as shown in the figure 159. Both the steam port and the exhaust port are now wide open and the piston is in the middle of its stroke. Any further movement of the crank towards the right will cause the valve to start on its return stroke. When the piston reaches the end of its travel toward the right, the eccentric will again be standing ver-



Engine With Square Valve Right Steam Port on Point of Opening. Fig. 160.

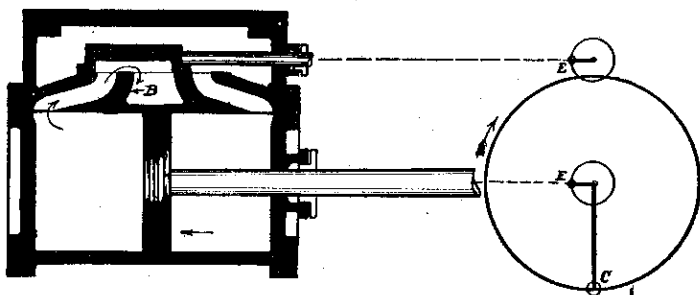
tically as at E, Fig. 160, and the valve will be in its mid travel just covering both ports.

- 26 The valve is now in position to admit steam to the right end of the cylinder and to let steam escape from the left side of the piston, through the left steam port, see fig. 161, by the inner edge of the valve, and over the bridge B, on the left, into the hollow part of the valve and down into the exhaust pipe. When the piston reaches the middle of its travel toward the left, the right steam port and the left

exhaust port are both wide open. As the piston advances, both ports begin to close, and when the end of the stroke is reached the valve is again in mid position as in fig. 158.

- 27 A little consideration of the above description and an examination of the accompanying diagrams reveals the fact that a "square" valve admits steam to the cylinder throughout the whole stroke and also allows it to exhaust during the whole stroke.

- 28 *Objections to the Square Valve.* Steam or any other gas



Square Valve, Right Steam Port and Left Exhaust Port Wide Open.
Fig. 161.

under pressure has a tendency to expand, and will do so unless imprisoned within strong walls. When steam is allowed to flow into the atmosphere it expands and its pressure falls until it has the same pressure as the atmosphere, namely 14.7 pounds per square inch. If it were allowed to expand into a vacuum, its pressure would fall until its pressure became practically nothing. If steam, at 100 pounds pressure be admitted behind a piston until

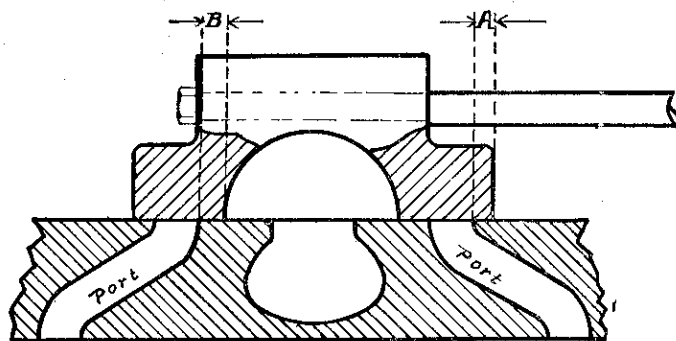
the cylinder is half full and the supply is then cut off, it will begin to expand and still drive the piston, but with a constantly decreasing pressure as the piston moves forward. At the end of the stroke it will still have some expansive energy left, but not so much as it would have if it were admitted during the whole stroke and exhausted at 100 pounds pressure at the end. Here is where the economy of working steam expansively comes in. When steam is exhausted at high pressure at the end of the stroke it has a large amount of energy which goes to waste. If it is expanded until its energy is nearly spent, a much less amount goes to waste. It pays to work steam expansively, and hence a square valve is not desirable except perhaps for slow moving pumps. The relations existing between the pressure and the volume of a gas will be discussed presently under the heading, "Boyle's Law."

- 29 *Cut Off.* There is an old saying that if steam is not used expansively it is used expensively. In order to use steam expansively, steam must be cut off quite early in the stroke; that is, it should be allowed to enter the cylinder during only part of the stroke, when the valve should close the port and prevent any more steam from entering the cylinder.

- 30 *Cushioning the Steam.* Likewise, the exhaust port should close before the end of the stroke is reached so that the steam left in the cylinder may be compressed or cushioned by the further movement of the piston, thus bringing the moving parts, such as piston, cross head, and connecting rod to rest without shock or jar at the end of each stroke.

If there were no steam cushion to arrest the motion of the piston and other moving parts at the end of the stroke, this task would then fall upon the crank pin. The blow struck on the crank pin due to the sudden reversal in direction of such a fast moving heavy mass will cause hot boxes, if the engine runs fast, and pounds or knocks at various places.

- 31 *Plain D Slide Valve with Lap.* An early cut off, the expansive working of steam, and the cushioning of the exhaust



A Plain D Slide Valve. Fig. 162.
With Both Outside and Inside Lap.

can all be provided for by giving the valve the right shape and setting both it and the eccentric properly. Fig. 162 shows how the valve should be changed. The metal which overlaps the steam ports on the outside, when the valve is in the mid position, is called the steam lap or outside lap, shown at A in the figure. The amount that the valve overlaps the steam port on the inside, is called the exhaust lap, or inside lap. This is shown at B.

Steam lap governs both the admission of steam to the cylinder and the cut off. Exhaust lap governs exhaust and compression.

- 32 *Lead.* The distance the valve has uncovered the port when the piston is at either end of its stroke, is called the *lead*. (See fig. 156.) The amount of lead a valve should have depends upon the design of the engine, the style of the engine, the style of the valve gear, and the peculiarities in the engine itself. From 1-32 to 1-16 of an inch is the usual lead given the valves of traction engines.
- 33 *Boyle's Law* states that if the volume of a gas be doubled, its pressure will be reduced to one-half, or, if the pressure

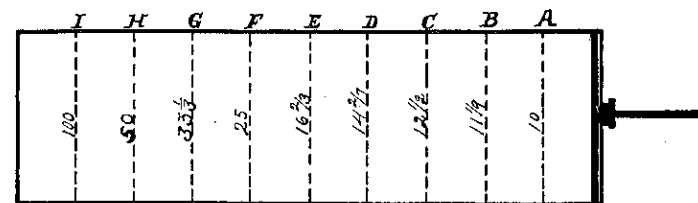


Fig. 163.
Diagram Showing Increase in Pressure Due to Compression.

be doubled, the volume will be reduced to one-half of the original amount. In other words, an exact relation exists between the pressure and volume of a gas. When the pressure goes up the volume goes down, and when the volume goes up the pressure goes down. That is, if the temperature does not change. For example, suppose a cylinder of ten cubic feet capacity be fitted with a piston and arranged as shown in fig. 163. Suppose, to begin with, that

the cylinder is filled with air or some gas at a pressure of ten pounds per square inch, absolute pressure. If the piston were pushed in to the point A, compressing the ten cubic feet to nine, the pressure would increase to ten times ten-ninths or 11 1-9 pounds. The following table shows the pressure at the different points along the cylinder, as the piston is pushed in and the gas is compressed. The table also shows how the change in pressure is figured.

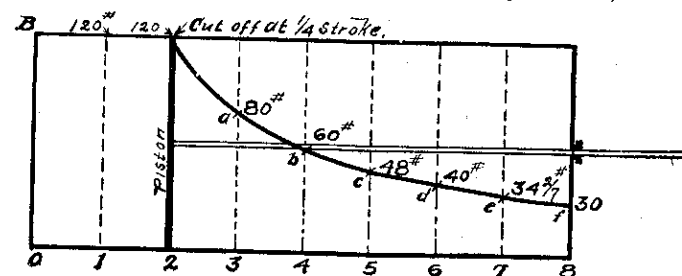
- A 10x10-9 equals 11 1-9 lb. F 10x10-4 equals 25 lb.
 B 10x10-8 equals 12 1-2 lbs. G 10x10-3 equals 33 1-3 lb.
 C 10x10-7 equals 14 2-7 lb. H 10x10-2 equals 50 lb.
 D 10x10-6 equals 16 2-3 lb. I 10x10-1 equals 100 lb.

Now let us figure how the pressure will fall when the gas is allowed to expand. Let fig. 164 represent the cylinder of a steam engine. Suppose steam at 120 pounds absolute pressure be admitted during $\frac{1}{4}$ of the stroke. Let it be required to find what the pressure will be in the cylinder at various points in the stroke during the expansion. The method of doing this is tabulated below:

POINT IN THE STROKE.	METHOD OF FINDING PRESSURE.	RESULT.
3-8	120x2-3	80 lb.
4-8	120x2-4	60 lb.
5-8	120x2-5	48 lb.
6-8	120x2-6	40 lb.
7-8	120x2-7	34 2-7 lb.
8-8 (end of stroke)	120x2-8	30 lb.

- 34 *Explanation.* In this discussion we are supposing that there is no clearance volume to be filled with steam. If

the total volume of the cylinder be divided into eight parts, it is evident that at 1-4 stroke, two parts will be filled with steam at 120 pounds pressure. If this steam be expanded until the cylinder is 3-8 full, the two volumes will be expanded to 3, consequently the pressure will fall to 2-3 of what it was in the beginning, that is, 2-3 of 120, or 80



Fall of Pressures Due to Expansion. Fig. 164.

pounds. If steam be further expanded until the cylinder is half full, the two volumes will be increased to 4, and so the pressure will fall to 2-4 or 1-2 of the original, which is 60 pounds.

- 35 *Rule 2.* Therefore, if we use the original volume for the numerator of a fraction, and the final volume for the denominator, and multiply the fraction so formed by the original pressure, the product will be the final pressure.

- 36 *Application of Boyle's Law.* In order to show the application of Boyle's law to problems of the steam engine, it will first be necessary to show that a force may be represented by a line. For example; suppose we represent a force of 100 pounds by a line 10 inches high. Then accord-

ing to the same scale 50 pounds would be represented by a line 5 inches high, or 10 pounds by a line one inch high. Or, we might change the scale and represent 100 pounds by a line one inch high, then ten pounds would be represented by a line 1-10 of an inch high. In like manner we may choose any suitable scale and represent pressures of varying amounts by lines of varying lengths, corresponding with the magnitude of the force. If it is agreed that forces and also distances may be represented by lines, it will be seen to be perfectly possible to represent the varying pressures on the piston of a steam engine by lines drawn to some convenient scale. This we will now proceed to do.

- 37 In fig. 164 let O8 represent the stroke of the piston, to some convenient scale, and let OB represent the pressure on the piston per square inch at the beginning of the stroke. If this pressure is 120 pounds per square inch, we can make OB two inches high, thus one inch measured in the direction of OB will represent 60 pounds. Since we have computed the pressure at eight different points, we will divide O8 into eight equal parts. Cut off occurs at 2, therefore, line O, 1 and 2 will each be two inches high. At 3 the pressure has fallen to 80 pounds, therefore, it must be made 1 1-3 inches high. At A the pressure is 60 pounds, which will be represented by a line one inch high. The pressures at 5, 6 and 8 are respectively 48, 40 and 30 pounds, represented by lines 48-60, 40-60 and 30-60 of an inch high respectively. In this way the points, a, b, c, d, e and f are located. If we join these points by a smooth curve, as is done in the figure, we can measure upward from the line

O8 to this curve and thus find the corresponding pressure for any point in the stroke. This curved line shows the fall in pressure during the expansion. All pressures measured in this way are absolute pressures, that is, they are 14.7 pounds greater than the corresponding gage pressure. To find the gage pressure, 14.7 must be subtracted from each of the pressures measured in the diagram. With the foregoing explanation it will now be easy to show the gain in economy by using steam expansively.

- 38 *Increase in Economy by Cutting Off Steam Early in the Stroke.* It must be remembered when reading the following discussion, that the results obtained are purely theoretical. They are not, and cannot, be exactly realized in practice because such perfect conditions cannot be found in any engine as are supposed to exist in the problem discussed. In the first place, the expansion of steam does not follow Boyle's Law exactly. In the second place, no clearance volume is taken into account, and in the third place, no losses due to condensation or loss of heat are considered. Nevertheless, if we find theoretically that we can gain a great deal by doing certain things, we know that practically we will also gain, but not to such a great extent. Theory often points the direction that must be taken to secure improvement and shows us the limit of perfection that may be reached.
- 39 In fig. 165, which is a diagram showing the pressures on the piston when taking steam full stroke, the line BC is parallel to AD, showing that the pressure does not fall after steam is admitted. The average pressure throughout the

stroke is, therefore, the same as at the beginning. If the pressure at the beginning of the stroke is 100 pounds, absolute, then the average pressure throughout the stroke is 100 pounds. In all of the diagrams, figures 166 to 169 inclusive, the same pressure at the beginning of the stroke will be used, namely, 100 pounds, absolute. In every case, also,

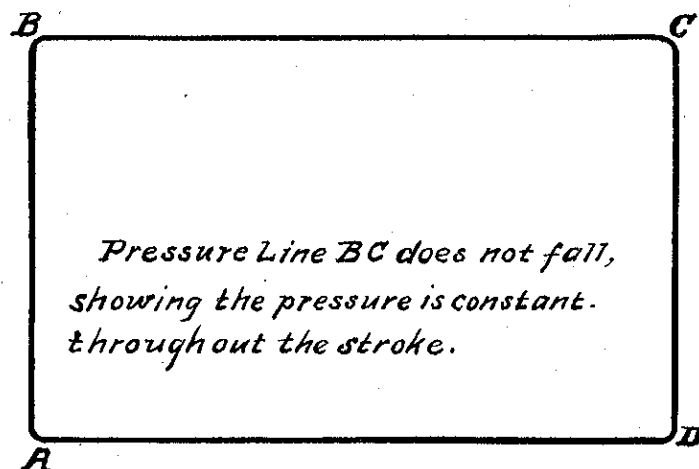
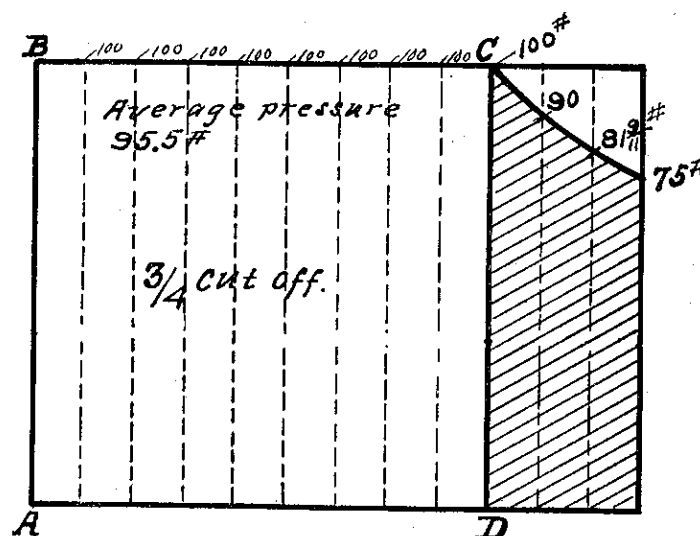


Fig. 165.

the pressure will be figured at twelve points along the diagram, at equal distances from each other. In this way we will figure the average pressure on the piston for the entire stroke, in each case.

40 *Cut Off at Three-quarter Stroke.* Fig. 166 shows the pressures in the cylinder when the steam is cut off at 3-4 stroke.

The pressure at each of the first nine points between B and C is 100 pounds. At the 10th division the pressure has fallen to nine-tenths of 100 or ninety pounds. At the 11th division the pressure is nine-elevenths of 100 pounds or 81 9-11 pounds, and at the end of the stroke, 9-12 of 100 or 75 pounds. The rectangle A B C D shows the work done

Diagram Showing Pressure Behind Piston for $\frac{3}{4}$ Cut Off. Fig. 166.

while steam is being admitted and the shaded portion the work done during the expansion. Adding the pressures at each of the twelve points of division, we get a total of 1146 9-11 pounds. If this sum be divided by twelve, the

number of divisions, the quotient will show the average pressure on the piston in pounds per square inch. The result in this case is a little more than 95 1-2 pounds. Theoretically, the average pressure on the piston for the whole stroke, when steam is cut off at 3-4 stroke, is a little more than 95 1-2% of the pressure before cut off.

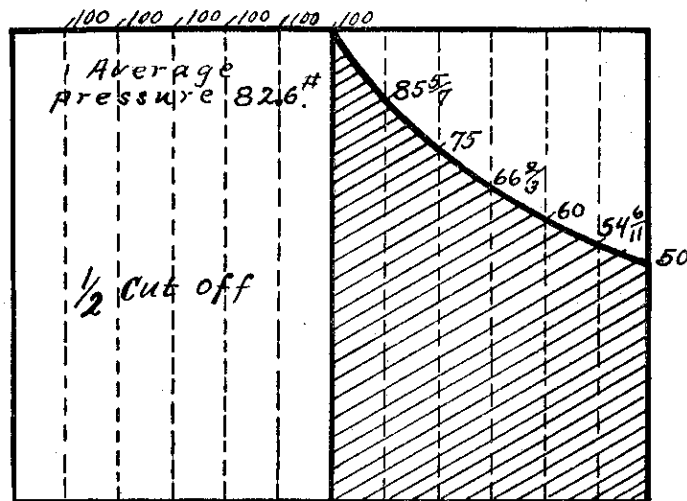
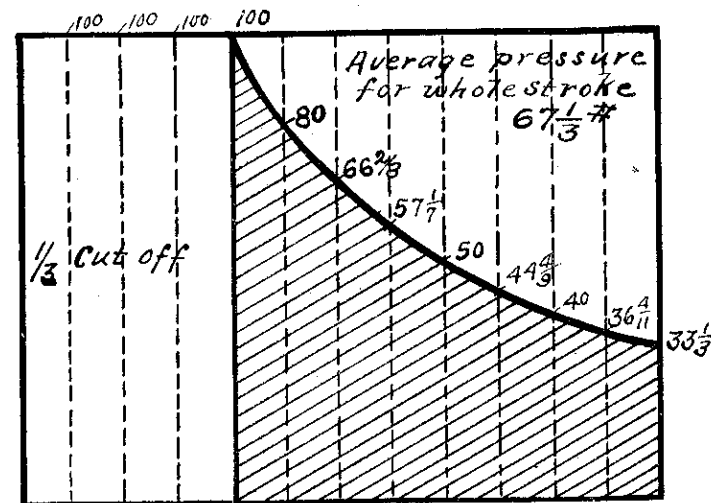


Fig. 167.

Pressures at Various Points in the Stroke—Cut Off at Half Stroke.

- 41 *Cut Off at Half Stroke.* Fig. 167 shows the pressures at different points in the stroke, when steam is cut off at half stroke. Adding all of these pressures together and dividing by twelve, the number of pressures added, gives an average of 82.6 pounds per square inch for the whole stroke. As

in fig. 166 the unshaded part represents to some scale the work done during the admission of the steam, and the shaded portion the work done during the expansion. The diagram shows that with one-half as much steam 82.6% as much work can be done, when the steam is cut off at half stroke. Of course, to realize such conditions in practice it would be



Pressures at Various Points in the Stroke—1-3 Cut Off. Fig. 168.

- necessary for the steam to exhaust into a vacuum, and even then the results would lack some of coming up to the theoretical figures. However, the diagram shows that there is much to be gained by the expansive working of steam.
- 42 Figures 168 and 169 show the pressures on the piston

for one-third cut off and one-quarter cut off respectively. The curved line shows the fall in the pressures after cut off in each case. The unshaded portion shows the work done by the steam before cut off, and the shaded portion the

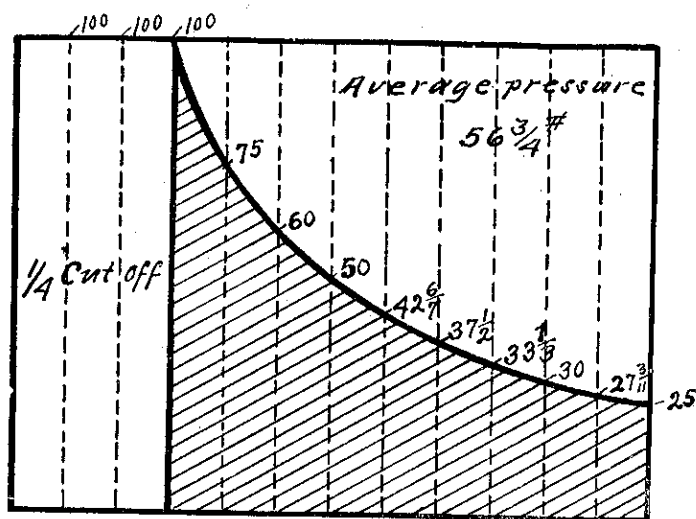


Diagram Showing Pressure Behind Piston for $\frac{1}{4}$ Cut Off. Fig. 169.

work done after cut off. In both cases the work done during expansion exceeds that done before cut off.

- 43 If more points of division were taken in the figures, the result would be more nearly correct. Table I shows the results obtained by an exact method of computation for different points of cut off, with steam pressures at 100 pounds, absolute, as before.

THE STEAM ENGINE.

Table I.

Theoretical Mean Average Pressure at Different Points of Cut Off.

POINTS OF CUT OFF.	THEORETICAL AVERAGE PRESSURE.
3-4	96.4
1-2	84.6
1-3	69.9
1-4	59.6

- 44 *Discussion of Diagrams.* At full stroke the average pressure on the piston was 100 pounds, and at 3-4 stroke, 95 1-2 pounds. That is, with 75% as much steam used, 95 1-2% as much work can be accomplished, theoretically.
- 45 At the earlier points of cut off the increase in economy is much greater. For instance, at 1-2 cut off, the average pressure is 82.6 pounds, which means that with 50% as much steam 82.6% as much work can be done.
- 46 At 1-3 cut off, 1-3 as much steam is used as at full stroke, and 67.3% as much work is done. At 1-4 cut off, 56 3-4% as much work is done as at full stroke, with 1-4 as much steam. Thus it will be seen that the earlier the cut off, the greater the *theoretical* gain in economy.
- 47 *Practical Limits of Early Cut Off.* It appears from the above discussion that the earlier the cut off occurs, the greater will be the gain in economy. This is found to be only partially true in practice. Making the cut off occur

earlier in the stroke improves the economy until somewhere about 1-4 cut off is reached, at which place the economy is greatest. Earlier cut off than 1-4 generally results in a loss of economy. This is due to a number of causes, most important of which are condensation in the cylinder and loss from work done by back pressure on the piston. Considerable depends, too, upon the type of the engine, and the care taken in its construction as well as the pressure at which steam is admitted to the cylinder.

48 In explanation of this latter point, namely, the pressure at which steam is admitted to the cylinder, we will assume that steam is admitted at 60 pounds, absolute pressure, and that cut off occurs at 1-4 stroke. At the end of the stroke, therefore, the pressure will be 1-4 of 60 or 15 pounds, absolute, or only a fraction of a pound above atmospheric pressure.

49 If the steam pressure were 50 pounds at the beginning of the stroke, and cut off occurred at 1-4, the pressure at the end of the stroke would be 1-4 of 50 or 12 1-2 pounds. In this case the pressure at the end of the stroke is less than atmospheric pressure, consequently the piston, at the end of the stroke, will be working against atmospheric pressure, of 14 7-10 pounds, with only 12 1-2 pounds to push it forward. Thus showing that back pressure on the piston is greater than forward pressure, and, consequently, the expansion of steam has been carried too far.

50 *Back Pressure.* If an engine exhausts into the atmosphere, the steam flows out into the air against atmospheric pressure and meets a resistance of 14.7 pounds per square

inch. In actual working conditions the steam meets more resistance than this, because of the relatively small size of the exhaust ports, which cause friction and consequent back pressure. The amount of this back pressure ranges from 1 1-2 pounds in the best engines, to 3 or 4 pounds in small ordinary engines. In traction engines and locomotives this back pressure amounts to from 5 to 8 pounds, due to the throttling of steam in the exhaust nozzle. The total amount of back pressure on a traction engine, therefore, amounts to from 20 to 22 pounds *absolute* pressure.

51 *Mean Effective Pressure.* The mean or average effective pressure, i. e., the pressure that does the work, is equal to the average forward pressure minus the back pressure. Consequently the average pressure on the piston as found by the foregoing diagrams, is from 20 to 22 pounds too high for traction engines. In other words, the effective, or working pressure, per square inch on the piston of traction engines is equal to the pressure above shown minus 20 or 22 pounds, depending on the size of the exhaust nozzle. It is best to use just as large an exhaust nozzle as possible and so reduce the back pressure as much as possible. Every pound of back pressure taken away is equal, at least, to a pound of forward pressure added. In consequence of this high absolute pressure of the exhaust it is evident that with low boiler pressure, the cut off must not occur too early. For example, if cut off occurs at 1-4 of the stroke, the final pressure must be 22 pounds, then the initial pressure must be 88 pounds, absolute, at least, or 73 pounds by the gage. An earlier cut off than this would carry the

exhaust pressure too low and no gain, but rather a loss would result in the last part of the expansion.

- 52 *Back Pressure in Condensing Engines.* If the steam as it exhausts from an engine cylinder could be delivered into a closed vessel where it could either meet a spray of cold water or strike a very cold surface, which is kept cold with flowing water, and thus be instantly condensed, the pressure in the vessel might be reduced to almost zero. In fact, many engines running with a condenser exhaust at a pressure of from 12 to 13 pounds below the atmospheric pressure. If the back pressure is reduced it is clear that it must amount to the same thing as adding an equal amount of forward pressure. Attaching a condenser to an engine increases its power, because it takes away back pressure. Condensers are not attached to traction engines and cannot be very easily because they require so much water to condense the steam. One pound of steam requires about 25 pounds of condensing water, therefore, a traction engine that would use five tanks of water a day with a condenser, would need an additional 125 tanks to condense the steam. It will thus be seen that the gain in using a condenser under such conditions, is more than offset by the increased cost of providing condensing water.

- 53 *The Angle of Advance.* Referring back to fig. 158, it is obvious that if the valve has lap, and is set with lead, that the eccentric must be rotated to the right far enough to move the valve from its central position an amount equal to the lap plus the lead. The angle between the 90° position and this new position of the eccentric, shown at A, in fig.

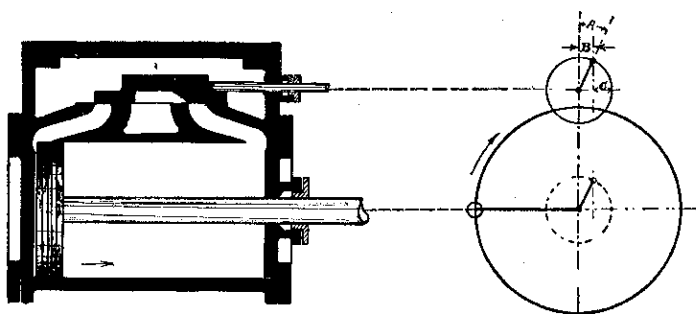
170, or at B, in fig. 177, is called the angle of advance of the eccentric. By increasing the angle of advance, it is obvious that the lead may be increased. Thus steam will be admitted earlier, and *release*, or the opening of the exhaust will be earlier. Likewise, the closing of the exhaust will occur sooner, and compression will begin earlier. In other words, if one function of the valve is made to occur earlier or later, all other events will also occur either earlier or later. As just shown, with a valve and valve motion like the one under discussion, these events may be regulated to some extent by changing the angle of advance. It must be understood, however, that this is true only for the kind of valve motion now under discussion. These remarks do not apply to some of the reversing motions found in traction engines.

- 54 *Travel of the Valve.* It is obvious that if the valve is provided with lap, and set with lead, that it must have more travel than a square valve. In the case of a square valve, the travel of the valve from mid position just equals the port opening. With a valve having lap and set with lead, the eccentric is moved over, a distance B, fig. 170, at the beginning of the stroke and, therefore, the length of throw must be increased, over that of the square valve by this amount, so that the remaining distance that the valve moves toward the right, C, will equal the width of the port.

- 55 *Action of a Valve Having Lap, set with Lead.* The following four figures, fig. 170 to 173 inclusive, show the positions of the valve, eccentric, piston and crank at four different points in the stroke.

56 In order to show the relative positions of crank and eccentric, the eccentric position is also shown at the centre of the crank circle. If the reader will make himself familiar with the relative positions of the crank and eccentric at the beginning of the stroke he can tell at a glance, within a very small amount at least, whether the eccentric is in its right position or not. He will not have to guess if the eccentric has slipped, he can tell by looking at it.

57 In fig. 170 the left hand steam port is opened the amount



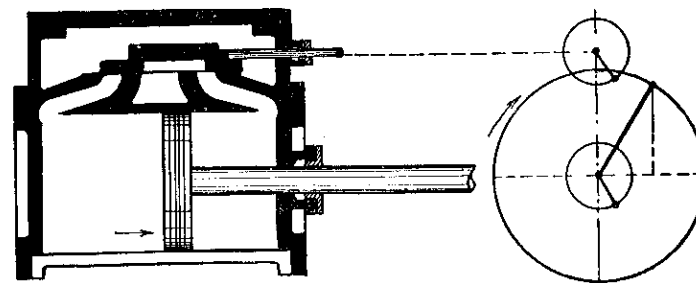
Valve with Lap, Valve Open the Amount of Lead, Beginning of Stroke. Fig. 170.

of the lead. The crank follows the eccentric, and hence rotation will proceed in the direction of the arrow. Since the crank and eccentric are both fastened to the same shaft, it is evident that the port will be wide open before the crank makes a quarter of a revolution, and that it will be closed again before the piston reaches the end of its stroke.

58 Fig. 171 shows the position of all parts when cut off

occurs. From the point of cut off until the end of the stroke expansion takes place.

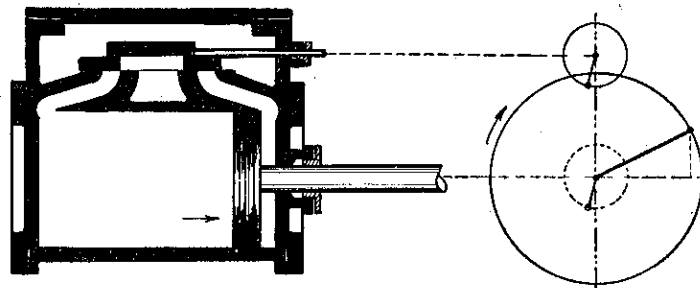
59 *Release.* The valve should open the exhaust port on the steam side of the piston just before the latter reaches the end of its stroke in order that there shall be the smallest



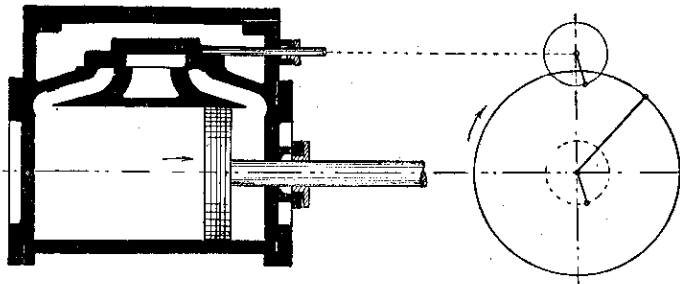
Left Steam Port Just Closed, Expansion Commencing. Fig. 171.

possible amount of back pressure when the piston first starts back. The point at which this opening occurs is called release. Fig. 172 shows the position of the piston and valve when this event occurs.

60 *Compression.* As indicated on a preceeding page, steam should not be allowed to exhaust up to the end of the stroke. By giving the valve the right amount of inside lap it is possible to make it close the exhaust port at the proper time, so that the remaining steam left in the cylinder will be compressed sufficiently to bring the strain of reversing the piston upon the cylinder head instead of upon the crank pin. The point at which the exhaust so closes is called the point of compression and is shown in fig. 173.



Valve with Lap, Left Exhaust Port on Point of Opening for Release. Fig. 172.



Valve with Lap, Compression Just Commencing. Fig. 173.

- 61 *Effect of the Angularity of the Connecting Rod.* The crank end of the connecting rod moves up or down past the centre line of the engine a distance equal to the length of the crank during every revolution of the engine, thus making an angle, which varies at different points in the stroke, with the centre line of the engine. In consequence of this

action the piston does not keep exact time with the crank. This is clearly shown in the accompanying diagram, fig. 174. The stroke of the piston is from A to B. If we move the piston to M, the mid point of its stroke, and then strike an arc with a pair of dividers set to the length of the connecting rod, we will find that this arc cuts the crank circle at C, thus showing that the crank has not yet made a quarter of a turn when the piston has completed half of its travel to the right. Now, if we move the dividers to D, and strike an arc across the centre line of the engine, we shall find that when the crank has made half of its travel from right

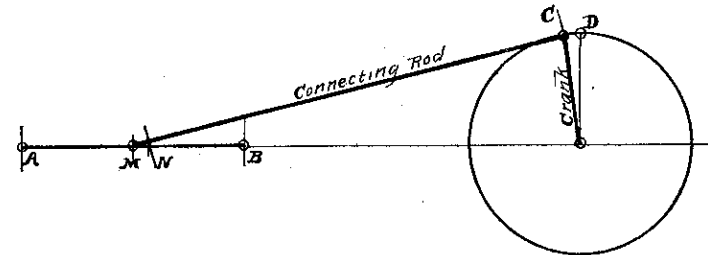


Diagram Showing Effect of Angularity of the Connecting Rod. Fig. 174.

to left, the piston has traveled a distance MN beyond centre. During the next quarter of a revolution of the crank the piston will complete its stroke, reaching the position B. Now, if the crank revolves at a uniform speed, as it should, it is plainly evident that the piston must travel faster at the head of the cylinder than at the crank end. It is also evident that if the connecting rod were very long,

as compared to the crank, that this difference would be very small. It is also evident that if the connecting rod could be arranged in some way so that it could always remain parallel to the centre line of the engine, and not make any angle at all, that the piston and crank would travel exactly in time with each other. In practice, however, this result cannot be obtained.

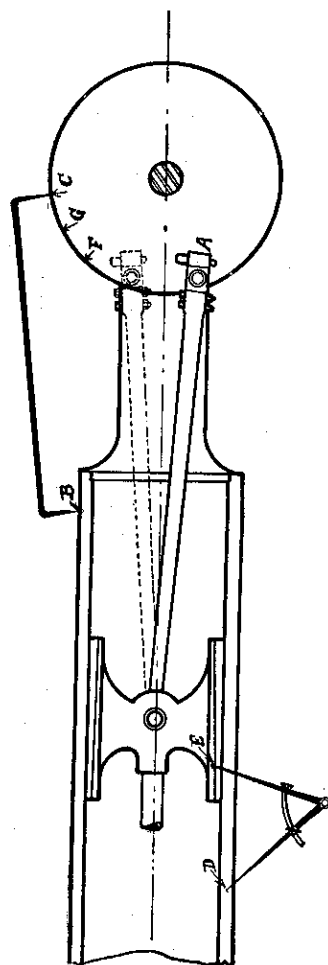
62 *Effect of the Angularity of the Connecting Rod on the Valve Motion.* Since both the eccentric and the crank are fastened to the shaft, and since the crank does not keep exact time with the piston, it must be evident that the *eccentric* cannot keep time with the piston. The valve is driven by the eccentric, and therefore the *valve* cannot move in exact time with the piston. Consequently, it is impossible to make the valve, when set with equal lead, in an engine such as we have been considering, cut off steam at the same point in both the forward and the backward strokes. For, as shown before, the piston gains on the crank at one point in the stroke and loses in another. We can, however, make the valve cut off steam equally on both strokes if we give it *more* lead on one side than on the other. We cannot have both equal lead and equal cut off. If we have equal lead the cut off will be unequal, and if we have equal cut off the lead will not be equal. It is better in most cases and gives a smoother, better running engine, to have equal lead regardless of the cut off, and so valves are usually set with equal lead. When set in this way, the engine does a little more work on the head-end stroke than on the return stroke.

63 *Dead Centre.* An engine is on dead centre when the

centres of the piston, crank pin, and main shaft lie in the same straight line, in which case the piston is at the extreme end of its travel in either direction. If an engine stops on dead centre, it cannot be started until turned off from centre by hand. The force of the steam does not have any turning effect on the crank when the engine is on centre. If it were not for the energy stored in the fly wheel, a simple engine could not pass the dead centre position. In order to set the valve or eccentric, it is necessary to put an engine on dead centre. Simply guessing at centre is not accurate enough because a slight movement of the crank near the dead centre positions causes a greater movement of the valve than at any other points in the stroke. One can rarely ever guess the exact dead centre position, so it is advisable always to put an engine on centre by means of trams. Such an operation is frequently termed "tramping an engine."

64 *Directions for Putting an Engine on Centre.* The method of performing this operation is shown in fig. 175, and explained below. The order of procedure is indicated in the explanation.

1. Take up all lost motion in the cross head, connecting rod, crank pin, and main bearings.
2. Turn the engine a little above, or a little below, centre. The crank will be at, say A, in the figure.
3. Make a punch mark on the engine frame at any convenient point as at B, then with a tram like the one shown in the figure, one end of which is held at B, make a mark C, on the rim of the fly wheel or crank disc.
4. Now make a punch mark on the cross head and



Method of Putting an Engine on Dead Centre. Fig. 175.

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another at some convenient place on the guides; as D and E, and set a pair of dividers with the points in these two marks.

5. Next turn the engine past centre until the cross head comes to the same position as before, and the points of the dividers will exactly fit into the two marks D and E. The crank is now on the other side of centre just exactly as far as it was past centre in the opposite direction.

6. With the end of the tram still in position B, make another mark F, on the rim of the fly wheel. Now find by careful measurement, a point on the wheel, G, exactly midway between C and F. If the engine is now turned until the points of the tram just fit into the marks B and G, the engine will be on dead centre. The other dead centre may be found by an exactly similar process. Now that it is understood how dead centre may be found, it will be easy to explain how to set a plain slide valve.

65 *Directions for Setting a Plain Slide Valve.* After taking up lost motion the first thing to do is to adjust the length of connections between the valve and the eccentric. To do this, and then set the valve and eccentric, proceed in the order given below.

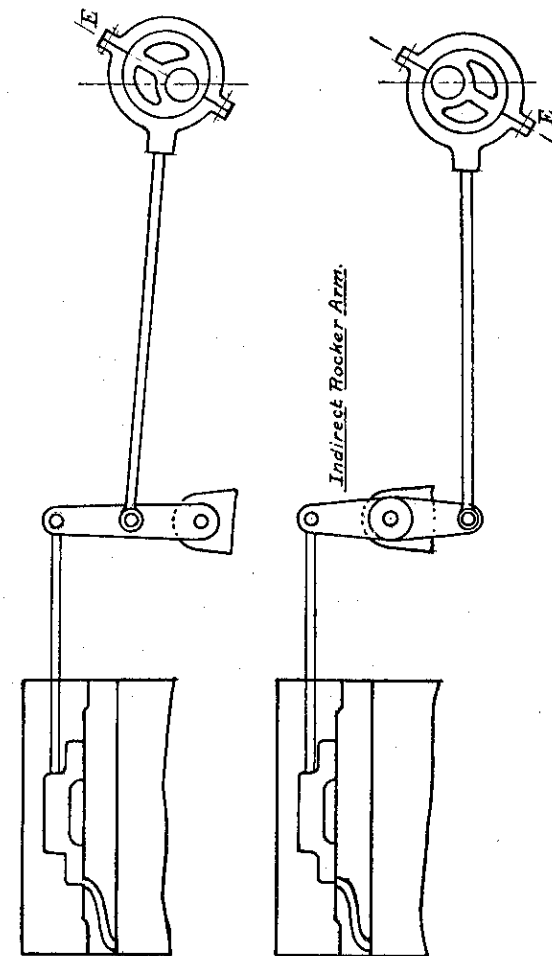
1. Loosen the set screws in the eccentric and turn it completely around the shaft and notice if the valve opens one port as wide as it does the other. If it does not do so, then move the valve on its stem or else change the length of the connecting rod until the valve will open both ports exactly the same amount. If the engine is not too large the eccentric may be secured to the shaft and the fly wheel turned around instead. The same result may be secured by either method.

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2. Now place the engine on dead centre by means of the trams and then set the eccentric. If no indirect rocker shaft intervenes between the shaft and the eccentric, then the eccentric must be placed with its arm or highest part a little more than a quarter of a turn *ahead* of the crank. With the crank on either dead centre, rotate the eccentric in the direction the crank is to revolve until the valve shows the proper amount of lead on the side next to the piston. Secure the eccentric in this position and put the engine on the other dead centre and see if the lead is the same. It will be if all measurements have been made accurately.

3. If there is a difference in the amount of lead, it may be made equal by correcting one-half of the error by changing the length of the connections and the other half by moving the eccentric.

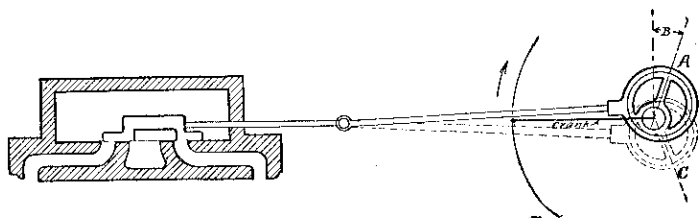
- 66 *Rocker Arms* are of two kinds, direct and indirect. A direct rocker arm either gives the valve more travel than the throw of the eccentric, or less, depending upon how the valve stem and eccentric rods are connected to it. The upper diagram in Fig. 176 shows a direct rocker arm in which the valve has a greater travel than the throw of the eccentric. The lower diagram represents an indirect rocker arm. Both rocker arms give the valve the same motion, but it will be noticed the positions of the eccentrics are exactly opposite one another. The direct rocker arm has the same eccentric position as though no rocker arm were used. In the case of the indirect rocker arm the eccentric is exactly 180° from the original position. When an indirect rocker arm is used the eccentric is located 90° minus



Rocker Arms and Eccentrics, Fig. 176.

the angle of advance *behind* the crank. With a direct rocker arm, or with no rocker at all, it is placed 90° *plus* the angle of advance *ahead* of the crank.

- 67 *Reversing a Plain Slide Valve Engine.* On an engine with no rocker arm, the eccentric is placed a little more than 90° ahead of the crank. *Ahead* in this case meaning in the direction of rotation. Consequently, if the eccentric is turned to position A in fig. 177, the engine will run



Position of Eccentric Shown in Dotted Lines When Engine is Reversed. Fig. 177.

in the direction of the arrow. If it is turned an equal amount past centre in the opposite direction to the position C, the engine will be reversed. To reverse an engine, therefore, put the engine on dead centre and rotate the eccentric in the direction it has been running, past the centre line of the engine until the valve shows the same amount of lead it had before.

QUESTIONS FOR LESSON VIII.

1. In how many and in what ways may steam engines be classified?
2. How may farm engines be classified?
3. Explain the difference between a compound engine and a double simple engine?
4. Name the parts which make up the fixed parts of a simple engine?
5. What parts constitute the valve gear of an engine?
6. When is an engine said to "run over?"
7. When is an engine said to "run under?"
8. Define clearance?
9. How is the size of (a) a simple engine designated, (b) a compound engine?
10. Explain what is meant by the "throw of the eccentric?" Explain the use of the eccentric?
11. Describe a square D valve?
12. What is the position of the eccentric relatively to the crank, when a square valve is used?
13. What are the objections to the square valve?
14. Define "cut off?"
15. What is the object of cushioning the steam?
16. Define (a) Steam Lap? (b) Exhaust Lap?
17. What is the object of giving a valve lap?
18. If steam or air, at 100 pounds absolute pressure expands

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- from two cubic feet to five, what will its pressure then be?
19. If three cubic feet of air, at 50 pounds absolute pressure be compressed to one-half a cubic foot, what will its pressure then be, assuming that there is no rise in temperature during the operation?
 20. Show, by means of a diagram, the fall in pressure of steam which is admitted to an engine cylinder at 100 pounds absolute pressure and is cut off at half stroke?
 21. Is there any theoretical gain in cutting off steam early in the stroke?
Give a brief explanation of it?
 22. Explain what is meant by the term "mean effective pressure?"
 23. What is meant by the term "Angle of Advance?"
 24. Why is an eccentric given angle of advance?
 25. What is the effect of increasing the angle of advance?
 26. What is meant by the term "release" as applied to engines?
 27. What is meant by the term "angularity of the connecting rod?"
 28. What effect has the angularity of the connecting rod on the distribution of steam in an engine cylinder?
 29. Explain how to put an engine on "dead centre?"
 30. What is the position of the eccentric, relatively to the crank, in the case of a valve which has lap?
 31. Explain the effect of an indirect rocker arm on the position of the eccentric?
 32. What must be done in order to reverse a plain slide valve engine?

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LESSON WITH QUESTIONS

COMPOUND ENGINE AND ENGINE
DETAILS
PART IX

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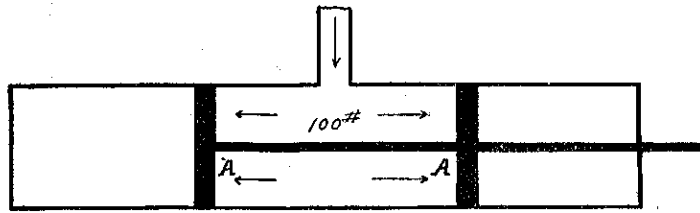
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PART IX.

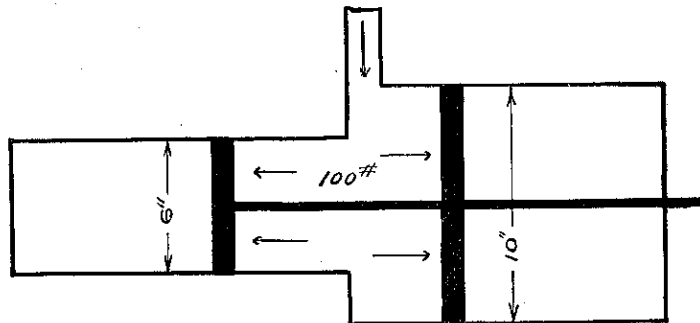
COMPOUND ENGINES AND ENGINE DETAILS. INTRODUCTION.

- 1** Compound engines, such as are used on traction engines, have two cylinders, one small, the other large. The small cylinder is called the *high pressure*; the large one the *low pressure* cylinder. Steam first enters the small cylinder, and after doing its work therein, is passed on to the low pressure cylinder, where it is expanded still further and does more work. In general, it may be said that compound engines take greater advantage of the expansive power of steam than do simple engines, and, for this reason, and other reasons which will be presented later on, they are considered somewhat more economical in the use of fuel. This is especially true of the large sized engines of fifty horse power and upwards.
- 2** There are two distinct types of compound engines, namely; tandem compound, and cross compound. Tandem compound engines have the cylinders placed end to end, while cross compound engines have the cylinders placed side by side. The pistons of tandem compound engines are necessarily secured to the same piston rod and, consequently, only one crank is needed. In the case of cross compound engines, on the other hand, the pistons are fastened to separate piston rods which are connected up to two cranks

placed 90° , or one quarter of a turn, apart. When one piston is at the end of its stroke, the other is in the middle. Both types of engines have points of merit peculiar to themselves, and both have been used extensively, not only



Steam Admitted Between Two Pistons of Equal Size. Fig. 178.



Steam Admitted Between Two Pistons of Different Size. Fig. 179.

on traction engines, but in stationary practice as well, where they have given very good and efficient service.

- 3 *The Size of Compound Engine Cylinders.* The diameters of the pistons of a compound traction engine are about

in the ratio of three to five, i. e., if the high pressure piston is made three inches in diameter, the low pressure piston must be about five inches in diameter, or in that ratio.

- 4 The areas of circles are proportional to the squares of their diameters, therefore the areas of the two pistons will be as three squared to five squared. Three squared equals nine, and five squared equals twenty-five. The ratios of the areas of the pistons are as nine to twenty-five. In other words, the five-inch piston is about 2.7 times as large as the three-inch piston. It is necessary that the pistons be of different diameters, because the effective work done on the low pressure piston is due to the difference in area between the two pistons.

- 5 This can be clearly shown by the aid of Fig. 178. Thus suppose steam to be admitted between the two pistons of the same area, as shown at A. With an arrangement of this kind it is evident that the pistons will not move in either direction, because the total pressure on both pistons is exactly equal and in opposite directions; but if steam be admitted between two pistons of unequal diameter, as in Fig. 179, movement will take place, because the total pressure on the large piston, acting toward the right, is greater than on the small piston acting toward the left. Consequently, both pistons will move toward the right, propelled by a force equal to the difference between the pressures on the two pistons. For example, suppose the pistons are six inches and ten inches in diameter respectively, and that the pressure is 100 pounds per square inch. The area of the six-inch piston is 28.28 square inches, and the area

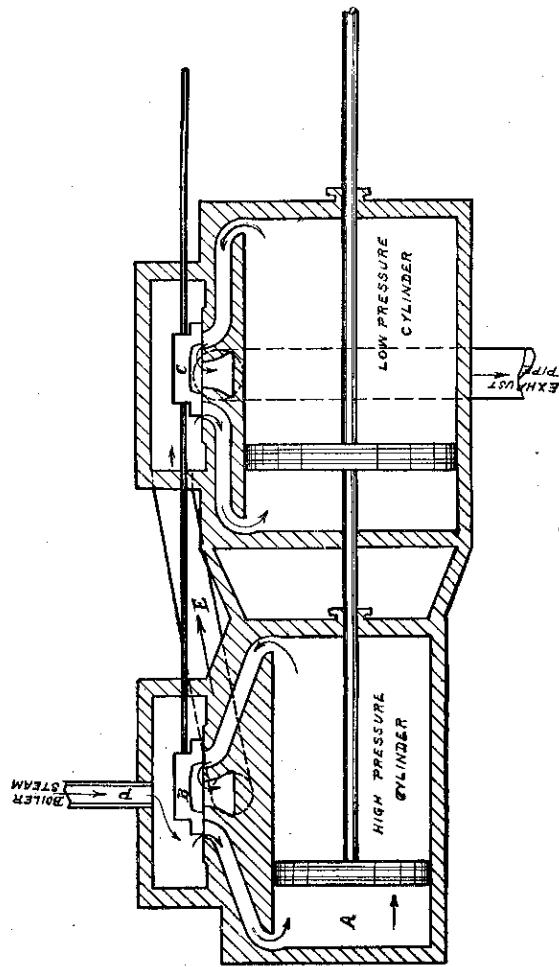


Diagram of a Tandem Compound Engine, Fig. 180.

of the ten-inch piston is 78.56 square inches. The total pressure on the six-inch piston, acting toward the left, is 28.28×100 or 2,828 pounds, while that on the ten-inch piston acting toward the right is 78.56×100 or 7,856 pounds. The force producing motion toward the right, therefore, is equal to $7,856 - 2,828$ or 5,628 pounds.

- 6 *The Action of a Tandem Engine.* Fig. 180 is a diagram of a tandem compound engine, showing the direction taken by the steam in passing through both cylinders, and, also, the action of the valves and pistons. The diagram shows each cylinder provided with a separate steam chest and valve. Steam enters the high pressure steam chest, through the pipe P from the boiler, and is admitted to the left end of the cylinder A, just as in a simple engine. The steam in the right end of A, left from the preceding stroke, passes out through the right hand port to the exhaust pipe E, which conducts it to the low pressure steam chest. Here it is admitted to the low pressure cylinder by means of a valve just as in the case of a simple engine. The valves B, and C, are given lap, and cut off the steam in both cylinders at the desired point. Steam is thus worked expansively in the high pressure cylinder, and then again in the low pressure cylinder. Since the low pressure cylinder is much larger than the high, it is evident that if steam were used full stroke in both cylinders, there would even then be considerable expansion, because the steam used in the small cylinder would have to expand and fill the large one. When steam is cut off before the end of the stroke in *both* cylinders, it is also clear that there must be still more expansion.

- 7 *Pressure in the Cylinders.* The pressure on the high pressure piston is the same as it is in the high pressure steam chest. If the engine is working hard, so that the governor valve is wide open, it is about the same as boiler pressure. The pressure on the low pressure piston at the beginning of the stroke and up to cut off, is nearly the same as the back or exhaust pressure on the high pressure piston. In other words, the forward pressure on the large piston is the same as backward pressure on the small at the beginning of the stroke. The pressure on the low pressure piston at the end of the stroke should be, and generally is, only a little above atmospheric pressure.
- 8 On account of the number of expansions in a compound engine, it is necessary that boiler pressure be quite high. It is not considered economical to work a compound engine on less than 120 pounds steam pressure. A simple engine, on the other hand, will work well on any pressure, high or low.
- 9 *The Course Taken by Steam in a Cross Compound Engine.* Fig. 181 is a diagram showing the course of steam through the cylinders of a cross compound engine. P is the admission pipe to the steam chest of the high pressure cylinder. Steam is admitted behind the piston A in the usual way, by means of a slide valve. At the same time the exhaust from the right side of the piston passes out through the exhaust pipe B, to the steam chest of the low pressure piston, from whence it is admitted to the low pressure cylinder by valve C. The pistons of a cross compound engine are connected with cranks set 90° apart,

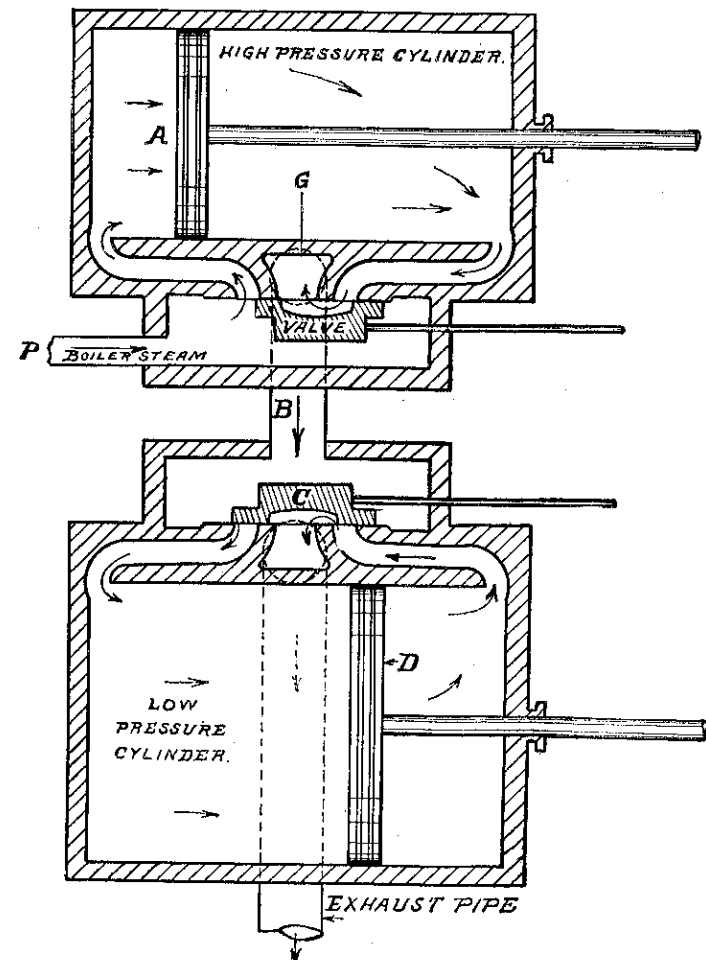


Diagram Showing Course of Steam Through a Cross Compound Engine. Fig. 181.

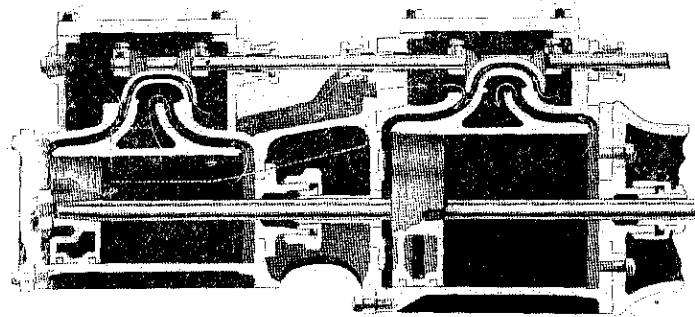
consequently when the high pressure piston is at the end of its stroke, the low pressure piston is at the midpoint of the low pressure cylinder. Thus one piston is exerting its maximum turning force upon the crank, when the other is at dead centre. When the low pressure piston D reaches the end of its travel toward the right, the high pressure piston is at the midpoint of the high pressure cylinder. The exhaust from the low pressure cylinder passes into the exhaust pipe and escapes up the chimney, just as in the simple engine. When the steam is cut off at one-half stroke in both cylinders, as it frequently is, the course of steam will be as follows: Starting with the pistons in the position shown in the diagram, steam will be admitted to the left hand side of piston A, until it reaches mid stroke. At the same time, valve C has just closed the left port of the low pressure cylinder. The exhaust from the high pressure piston, until the piston reaches point G, will now be forced into the low pressure steam chest, where the pressure rises until the valve C opens the right hand steam port. When this occurs, the piston D has reached the end of its stroke, and is ready to start on its return stroke toward the left.

- 10 *Tandem Compound Engines* may be divided into two classes. In the first class there are two cylinders placed some little distance apart, each provided with a separate steam chest and valve. In the second class, known as the Woolf Compound engine, the two cylinders are placed close together, having a common cylinder head between them and provided with only one valve and one steam chest. Fig.

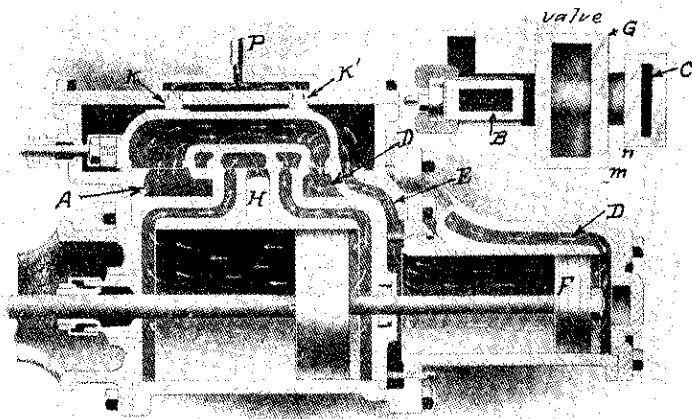
182 is a sectional view of an engine of the first named class that is used on a well known make of traction engine. With the explanation given for Fig. 180 in mind, the student will have no difficulty in tracing the direction taken by the steam. Particular attention is directed to the design of the stuffing boxes, and of the valve.

- 11 *The Woolf Compound Engine.* Fig. 183 shows the cylinders of this type of engine sawed in two lengthwise, revealing the interior construction of pistons, valve, and steam chest. The valve is shown entire above the small cylinder, and also sawed in two, and in place in the steam chest. All the steam that comes from the boiler passes from port A, which is cast as a part of the steam chest, and into the interior of the valve through the port B. This port B is large enough so that it always covers port A, no matter which way the valve travels. After passing through the valve, the steam emerges through port C, and passes, by means of ports D or E, either to the right or left end of the small cylinder, depending upon the position of the valve and pistons. As shown in the figure, steam is flowing through port D to the right side of piston F, while the exhaust is passing out through E into the steam chest. When the piston F arrives at the opposite end of the cylinder, the valve will have moved to the right until port C covers port E, when steam will be admitted to the left end of the cylinder and the exhaust will pass out through D into the steam chest between the rectangular parts of the valve, m and n.

- 12 Steam from the steam chest is admitted to the low pres-



Section of Cylinders and Valves of a Tandem Compound Engine.
Fig. 182.



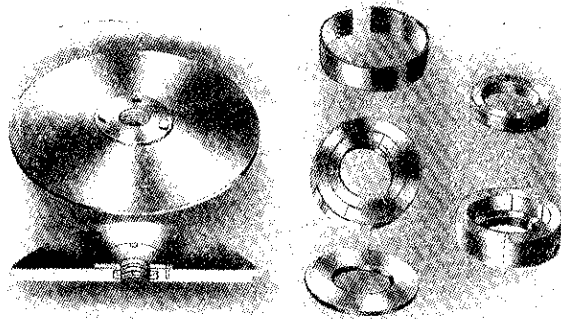
Section of Cylinders and Valves of a Tandem Compound Engine.
Fig. 183.

sure cylinder just as in the case of a plain slide valve engine. The large part of the valve G is nothing more than an ordinary plain slide valve which controls the admission and the exhaust of steam in the low pressure cylinder. The exhaust from the low pressure cylinder passes out through the port H to the chimney.

- 13 Since there is steam pressure on the inside of the valve pushing it away from its seat, it is necessary to put more pressure upon its back than what is afforded by the exhaust steam from the high pressure cylinder. This is accomplished by two small pistons, K and K', in the steam chest cover, which press against the valve by the force of live steam which enters from the boiler through the pipe P. If steam is not admitted behind K and K', the valve will sometimes pound against the seat when the engine is running. This is caused by the valve lifting from its seat, on account of too much pressure on the inside, and then dropping back under the influence of the exhaust from the high pressure cylinder.
- 14 *The Centre Head.* The head between the two cylinders is made steam tight by means of spring metallic packing, an illustration of which appears in Fig. 184.
- 15 *Cylinder Condensation.* When steam is admitted into a cylinder which is colder than itself, it will part with enough of its heat to raise the cylinder walls to its own temperature. In doing so a part of the steam will be condensed to water, which will form a thin film on the sides of the cylinder. This is called *initial* condensation and is responsible for a considerable loss in heat and consequent loss of efficiency

of the engine. Whatever heat is lost in this way is almost a total loss. It seldom amounts to less than 10 per cent in any engine, and may be much more.

- 16 When steam exhausts into the air, its temperature falls to 212° , and consequently the temperature of the cylinder



The Centre Head and Metallic Packing of Woolf Compound Engines. Fig. 184.

falls a considerable amount. When new steam re-enters through these same ports it must part with enough heat to warm them again, and thus condensation takes place.

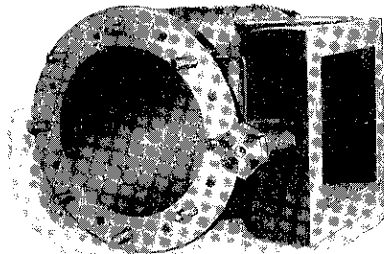
- 17 Ever since Watt's day engineers have been seeking a way to supply the cylinder with dry steam, and to keep it dry, for therein lies the secret of using steam economically. The means adopted to secure this result in traction engines are as follows:
- 18 1st. Taking steam from the top of the dome where it is dry and keeping it dry on its way to the boiler, by (a) making the steam pipe short and direct, and covering it

with some non-conducting substance, such as hair felt or asbestos. (b) Carrying the steam from the top of the dome inside of the boiler, and then bringing it to the steam chest by the shortest path, leaving as little exposed as possible, and covering what is exposed with a jacket.

- 19 2nd. *Jacketing the Cylinder* either with asbestos, felt, wood, paper, etc., as is usually done, or with a live steam jacket.
- 20 3rd. *Cushioning*, that is, compressing the exhaust. This is accomplished as previously explained by adding inside lap to the valve.
- 21 4th. *Superheating*. Some traction engine builders provide a super-heater pipe, or chamber, placed in the path of the hot gases, which heats the steam on its way from the boiler to the engine.
- 22 5th. *Compounding*. Each of these different methods will be described and discussed separately.
- 23 *Loss Due to Wet Steam*. The question is often asked, why is wet steam, or steam containing water, the cause of so much loss in an engine? The answer to this question is that when the walls of the cylinder become wet, they radiate and conduct the heat away a great deal more rapidly than when dry. This is why either initial condensation or priming causes so much loss.
- 24 *Jacket on the Cylinder and Steam Pipe*. The jacket on the cylinder consists of, first, an air space, then a covering of wood, next a layer of sheet asbestos, and lastly, a casing of sheet steel held in place by metal bands. The dead air space is itself a good insulator, and prevents the wood from

charring. A jacket of this kind prevents a great deal of radiation from the cylinder and adds to its appearance. The steam pipe covering is usually some preparation of magnesium or asbestos, held in place either by canvas or a thin metal covering. Where the pipe is long it should always be jacketed to prevent condensation as much as possible. In some engines the steam pipe is carried inside of the boiler in order to avoid condensation entirely.

- 25 *Jacketing the Cylinder with Live Steam.* Fig. 185 shows a traction engine cylinder provided with a live steam jacket.



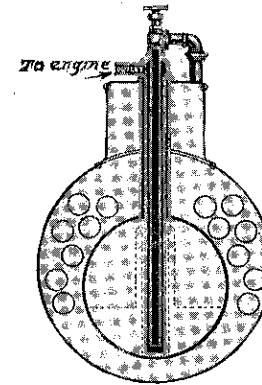
Cylinder with Live Steam Jacket. Fig. 185.

The cylinder is cast with hollow walls so that steam from the boiler can circulate all around the inner cylinder. The pipe which supplies this space slopes sharply back to the boiler so that any water which condenses in the jacket will flow back to the boiler by gravity.

- 26 Since the inner cylinder is surrounded by steam at the same temperature as that in the boiler, it is maintained at practically constant temperature. During expansion when the temperature in the cylinder falls it will draw heat from

the jacket. Consequently, there will be little or no initial condensation. There will be some loss of heat through radiation and condensation, however, in the jacket, which cannot be avoided. In Fig. 187 both cylinders of the cross compound engine are jacketed by the exhaust steam from the low pressure cylinder, which first circulates around the cylinder before passing out through the exhaust nozzle.

- 27 *Superheating.* Steam in the presence of water from



One Style of Superheater. Fig. 186.

which it is formed, as, for example, boiler steam, is said to be *dry saturated* steam. If this steam were heated still more, but not in the presence of water, it would become *superheated* steam. Steam that is superheated must lose all of its super-heat before it begins to condense. It is clear that if super-heating be carried high enough, initial condensation could be entirely overcome, that is, if the

steam contained enough additional heat to warm the cylinder walls, before all of this extra heat was used up. Even if the super-heater evaporates what water goes over with the steam as priming, it does some good. In stationary practice a super-heater consists of a coil of pipe, placed in the path of the hot gases, through which the steam passes on its way to the engine. The only objection to super-heaters is that they burn out quickly.

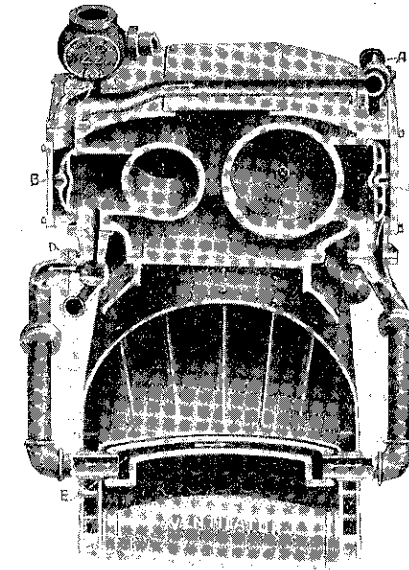
28 Fig. 186 illustrates a super-heater used on a certain traction engine. Steam passes from the dome through the inner pipe, down into the main flue and then back between the inner and outer pipes to the boiler. The principal object of this type of super-heater is evidently not so much to super-heat the steam as it is to evaporate the priming.

29 Fig. 187 represents another type of super-heater which is also a *re-heater*. This is used on a cross compound engine. The exhaust from the high pressure cylinder passes through a large casting in the upper part of the fire box, shown at E in the figure, where any water it may contain from condensation in the high pressure cylinder will be re-evaporated, and the steam given a few degrees of super-heat.

30 *Cushioning the Exhaust.* The exhaust port is closed, in most engines, before the end of the stroke and the steam then remaining in the cylinder is compressed by the force of the steam on the opposite side of the piston. When steam is compressed its temperature rises and thus the exhaust ports are warmed to some extent before new steam enters, thus preventing a considerable amount of initial condensation.

31 *The Effects of Compounding.* The compound engine en-

ables the fullest advantage to be taken of the expansive power of high pressure steam, and at the same time reduces initial condensation. Initial condensation is reduced largely by reducing the range in temperature in each cyl-



Cross Compound Engine Showing Superheater, Intercepting Valve, and Steam Jacket for Cylinders. Fig. 187.

inder. For example; suppose steam having an absolute pressure of 140 pounds, and a corresponding temperature of 352.8 degrees were to be used, and, suppose further that it passed on to the next cylinder at a pressure of 70 pounds

and a temperature of 302.7 degrees, and that it expanded down to 25 pounds with a temperature of 240.2 degrees in the low pressure cylinder. In passing it may be observed that a certain temperature always accompanies a certain pressure in the case of steam. The difference in temperature between the two ends of the high pressure cylinder under the above conditions is 40.1 degrees, and in the low pressure cylinder the difference is 62.5 degrees. The initial condensation, therefore, will be much less than if all the expansion occurred in one cylinder; the same is true of the low pressure cylinder. Furthermore, when steam expands from the high pressure to the low pressure cylinder, the pressure falls and the steam of higher pressure, which contains pound for pound more heat than that of lower pressure, turns the condensed water into steam. Consequently, the steam that goes to the low pressure cylinder is almost as dry as boiler steam, and really about all the loss through initial condensation occurs in the low pressure cylinder, i. e., if the engine is correctly designed.

32 If all the expansion from 140 pounds pressure to 25 pounds, occurred in one cylinder, the difference in temperature between the two ends would be 112.6 degrees, and the initial condensation would be considerably greater and the loss proportionally more.

33 It is a well known fact that the rate at which heat will flow from a hot body to a cold one depends upon the difference in temperature between them. If the difference is large, the rate of flow will be large; if the difference is small, the heat will flow slowly. Applying this principle to the

compound engine we can readily see that since the difference in temperature between the cylinder and the steam is smaller than in the simple engine, the rate at which the heat will flow will be correspondingly less. Furthermore, the cylinder walls do not heat up and cool down instantaneously, and so with a small range in temperature between the steam and the cylinder walls there will not be very much cooling during the exhaust. In the case of the simple engine, where the range in temperature is as great as it is in both of the cylinders of the compound engines taken together, the rate at which the heat will flow from the cylinder walls to the steam during expansion, and the amount the walls will cool will be much more than in both cylinders of the compound engine. Consequently, a great deal more heat will be needed to re-warm the exhaust ends of the simple engine than of the compound, and this causes greater initial condensation.

34 *Mechanical Advantages of Compounding.* Compound engines cause less strain on the bearings and on the main shaft than do simple engines of the same power. In the case of cross compound engines the cranks are set 90° apart, thus when one piston is passing centre, the other is exerting its greatest twisting effort on the crank. Therefore, there is no point in the stroke where there is no turning force exerted on the main shaft as in the case of a simple engine when the crank is passing centre. In consequence of this more even distribution of the twisting effort on the crank, there is less strain on the main bearings than in the case of a simple engine. A cross compound engine will

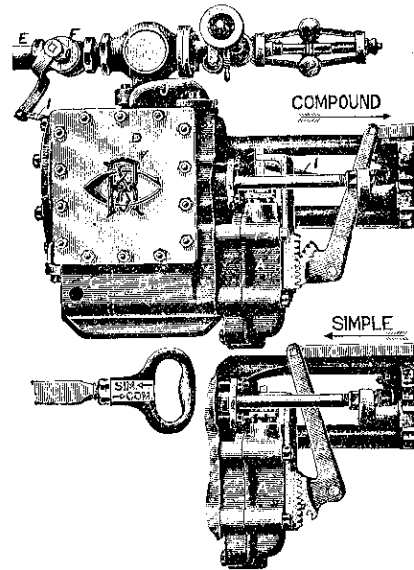
run steadier than either a simple or a tandem engine, and with a lighter fly wheel. The twisting effort on the crank in the case of a tandem engine is, however, more evenly distributed throughout the stroke than in a simple engine, because the initial pressure at the beginning of the stroke is higher and the terminal pressure lower. This can be easily shown by a few simple calculations.

- 35 It is usual to assume that a simple engine whose cylinder has the same dimensions as that of the low pressure cylinder of a compound engine has the same power as the compound. With this assumption we will proceed with the calculations. Suppose the area of the high pressure piston is 24 square inches, and that of the low pressure piston 72 square inches, and that the initial pressure on the high pressure piston is 140 pounds, and on the low pressure piston 70 pounds. The total pressure on both pistons is 24×140 plus 72×70 or 8,400 pounds. At the end of the stroke the pressure on the high pressure piston is 70 pounds, and on the low, 25 pounds, thus causing a total pressure on both pistons of 24×70 plus 72×25 , or 3,480 pounds. If the simple engine of the same power had a cylinder of 72 square inches working between the same ranges of pressure, the total initial pressure would be 140×72 , or 10,080 pounds, and the final pressure, 25×72 , or 1,800 pounds. Thus it will be seen that the initial pressure would be higher in the case of the simple engine and the final pressure lower than for a tandem compound engine. A tandem engine ought, therefore, to run steadier than a simple engine, on account of the better distribution of the

pressures on the pistons during the stroke, but not quite as steady as a cross compound. The fly wheel can be lighter and the load on the bearings and their tendency to heat will be less than for a simple engine of the same power.

- 36 *Intercepting Valves.* A cross compound engine is just as apt to stop on dead centre as a simple engine. If there is no steam in the low pressure cylinder, and the high pressure piston is at the end of its stroke, then the engine cannot be started as a compound engine, because all the steam that reaches the low pressure cylinder must first pass through the high. Since the high pressure piston is on centre, any steam admitted behind it will not cause motion. If, however, steam were admitted to the low pressure cylinder, its piston, which is at its mid stroke, would be in position to start. Just as soon as it moves the high pressure piston will also move and the engine can then run in the usual manner. All cross compound engines, therefore, are provided with what is called an intercepting valve, which enables the engineer to turn boiler steam into the low pressure cylinder until the engine starts and then, when motion begins, to shut it off and convert the engine into a regular cross compound.
- 37 Fig. 188 is an illustration of the intercepting valve used on a well known cross compound traction engine. It consists of a slide valve working in the chamber A. This valve is operated by means of a bell crank lever B, having a toothed sector which moves a sliding piece that is attached to the valve stem. Bell crank B is operated by a foot lever on the engineer's platform which is connected to rod C. The valve operated by B is so arranged that when it is

pushed down it turns live steam into the low pressure cylinder, and at the same time allows the exhaust from the high pressure cylinder to go out through the chimney, thus converting the engine into a double simple engine. When the engine is run in this way, it has a great deal more power than when running compound, a fact that is often

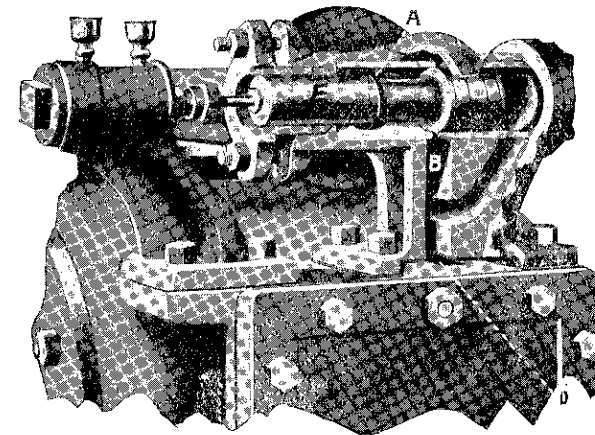


One Style of Intercepting Valve. Fig. 188.

taken advantage of in getting out of a bad place, where a large additional amount of power is required for a short time. The engine, when running as a duplex engine in this way,

of course, uses a great deal more steam than when running compound, and the pressure in the boiler will quickly run down because enough steam cannot be generated fast enough to meet the additional demand of the large cylinder.

38 Another style of intercepting valve is shown in figure 187, and again in figure 189. This engine can be turned into



Another Style of Intercepting Valve. Fig. 189.

a double simple engine by opening the three-way valve D, (fig. 187) which turns the exhaust from the high pressure cylinder directly up the smoke stack and at the same time shuts off the passage through the superheater E and prevents steam from going over to the low pressure cylinder. The intercepting valve is shown separately in Fig. 189, mounted over an opening in the low pressure steam chest.

Live steam enters the body of the intercepting valve through port A, and causes the piston E to move to the right and allow steam to flow through port B to the steam chest. At the same time steam from the steam chest flows back through port C, to the right side of piston E, and tends to close it against boiler steam. Since the area against which steam can act is greater on the right of E than on the left, it is clear that a much lower pressure in the steam chest will force E sufficiently to the left to close port B. The result of this arrangement is that the pressure in the low pressure steam chest will never fall below a certain amount, which amount depends upon the relative sizes of the right and the left hand sides of valve E. If there is enough exhaust from the high pressure cylinder to maintain this required pressure, port B will remain closed, but if there is not, then the intercepting valve, or, to be more exact, the *pressure equalizing valve*, E, will admit fresh steam to the low pressure cylinder. When the engine is working as a double simple engine, it cannot have full boiler pressure in the low pressure cylinder for the reason above given. The object of using an intercepting or equalizing valve of this kind is to so proportion the steam pressure as to make both pistons do an equal amount of work. If a little high pressure steam is needed in the large cylinder to equalize the load, the intercepting valve supplies it in the manner described above.

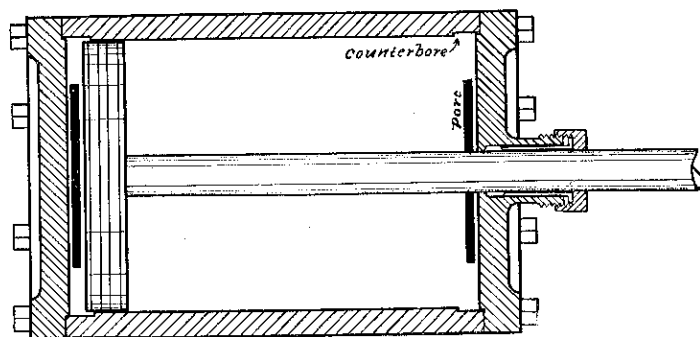
- 39 *Clearance.* As stated on a previous page in these lessons, clearance volume should be made as small as possible in order that the engine may be run with the smallest amount

of steam per horse power, and that it may be enabled to yield the greatest efficiency. If the engine took steam full stroke, whatever steam was required to fill the steam port passages and the clearance space at the end of the cylinder would be exhausted into the atmosphere at the end of the stroke, and thus be a total loss. When steam is used expansively this loss on account of clearance is considerably less, because after cut off all the steam behind the piston expands and is thus utilized to do work. In this way the steam in the clearance space is made some use of after cut off, but does no work before. It will readily be seen from the above brief explanation that long steam ports impair the economical working of an engine to some extent, causing it to consume more steam per horse power than it would if the clearance volume were smaller. Likewise the loss from initial condensation will be greater with a large clearance volume than with a small, because there is more surface for the steam to come in contact with. In the best makes of stationary engines the matter of clearance volume is one that is given a great deal of attention.

ENGINE DETAILS.

- 40 *The Cylinder.* The cylinder of a steam engine is the closed vessel in which the piston moves forward and back. It is made of hard close-grained cast iron, and bored out as smooth as possible in order to make a good surface for the piston to slide on. The ends of the cylinder are bored out about $\frac{1}{4}$ of an inch in diameter larger than the main body, and back a distance from the ends sufficient for the first ring on the piston to pass into this larger portion a

distance of about $\frac{1}{8}$ of an inch. If the cylinder were not counter-bored the piston rings would, in the course of time, wear the inside of the cylinder a little, forming a shoulder at the end of the stroke against which they would strike on every forward and back movement, thus making a pounding sound which it would be impossible to prevent. An illustration of the interior of a cylinder, showing the counter bore and the position of the steam ports is shown in Fig. 190.

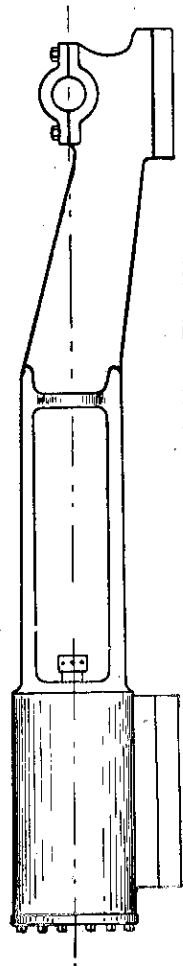


Section of Engine Cylinder Showing Steam Ports and Counterbore. Fig. 190.

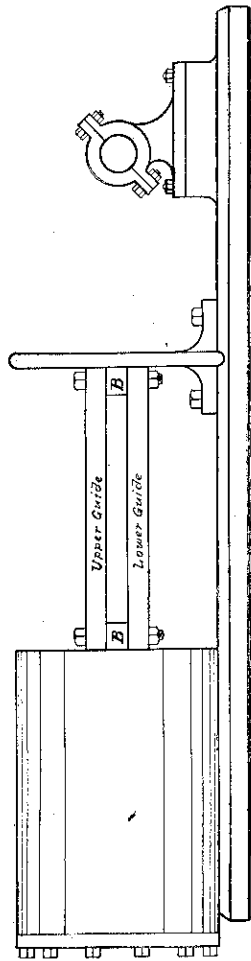
- 41 *The Engine Frame.* The engine frame consists of a heavy casting which is secured to the boiler by means of cap screws which pass through the flanges on the frame, and are screwed into the boiler shell. In most traction engines built at the present time, the cylinder, guides, and brackets, which fasten the engine to the boiler are cast in one piece. In some engines both bearings for the main

shaft are cast with this frame. Where the cylinder and guides are cast together, they are bored out at one setting with the same boring tool, and hence both cylinder and guides are bound to be in exact alignment. Where the cylinder is bolted to the frame and the guides are bored, it is usual to fit the cylinder in position first, and then bore both it and the guides together. Fig. 191 is an illustration of an engine having bored, or Corliss guides as they are sometimes called. Engines built in this way have certain advantages which make them peculiarly well adapted for traction engine purposes. These advantages may be enumerated as follows: 1st, the cylinder and guides are in perfect alignment, as both are bored at one setting with the same boring tool; 2nd, the engine is very rigid and strong, and not liable to get out of adjustment, because it contains the fewest possible number of joints; 3rd, bored guides are cheap to construct and present a very large bearing surface for the cross head, so that even if used for a considerable number of years, there will be little danger of their becoming badly worn, or worn out of line. In case they do wear there is, of course, only one remedy—and this may be urged as a possible objection, that is, they must be sent to a machine shop to be re-bored.

- 42 *Locomotive Guides.* Fig. 192 shows an engine fitted with Locomotive guides. This name is applied to them because they are used almost exclusively on locomotives. As will be observed, on referring to the drawing, they consist of heavy parallel steel bars, bolted to the frame at each end and held the required distance apart by means of distance



Engine with Bored Guides. Fig. 191.



Engine with Locomotive Guides. Fig. 192.

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blocks B. They possess one advantage and that is that when they are worn the parallel bars may be taken out, planed, and refitted in position just as good as new. Their proper adjustment being obtained by putting in shimming between the blocks and the parallel bars. The objection to their use lies in the fact that there are a large number of joints to be made and the difficulty of obtaining perfect alignment in consequence thereof, and, furthermore, the fact that the engine frame is not nearly so stiff or rigid as in the case of the bored guides. Taken all in all, the bored guides seem to possess advantages for traction engine work not possessed by the Locomotive guides.

- 43 *Side Crank Engines.* An engine having a crank disc, or crank at the outer end of the shaft, is called a side crank engine. Most simple engines and tandem compound engines are constructed in this way. Such an arrangement makes it necessary to mount the engine on the side of the boiler, thus leaving the whole top of the boiler unobstructed and providing room for the arranging of the necessary piping and levers in a convenient manner.
- 44 *Centre Crank Engines* are mounted directly on top of the boiler and therefore require a different kind of a crank shaft, since the cranks are placed between the bearings. They possess an advantage in thus causing the load or thrust of the piston to be distributed equally between the two bearings instead of all on one, as in the case of the side crank engines. All cross compound and double cylinder simple engines are mounted in this way.
- 45 *The Piston.* The piston consists of a short cylinder of

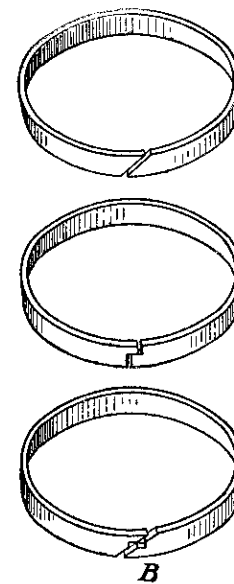
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cast iron, usually cast hollow to reduce the weight to the smallest amount. If this were not done, the weight of a heavy solid block of casting, resting on the bottom of the cylinder and working back and forth, would, in the course of time, wear the cylinder out of round. The piston is turned about $1/32$ of an inch in diameter smaller than the bore of the cylinder, and a steam tight fit is secured by the use of spring rings which fit in the grooves in the piston. In ordinary sized steam engines two rings are used; gas engines require from four to six.

- 46 *The Piston Rings.* The piston rings are made of cast iron and turned first as a solid ring, about $1/8$ inch in diameter larger than the bore of the cylinder. They are usually made a little thicker on one side than on the other. They are then cut in two at their thinnest place, and a portion removed at this point long enough so that when the ring is sprung together it will be a tight fit in the cylinder. The method of cutting this ring varies according to the ideas of the designer as illustrated in the accompanying drawing, Fig. 193. When cut as shown at B, it is necessary to insert a pin in the groove in the piston about which the notch in the piston ring fits. When the rings are inserted in this way the joints in the rings are made to come on the opposite sides of the piston. When the piston rings are properly turned up and fitted, they should be sprung together and returned to the same diameter as the bore of the cylinder in order to make a perfect fit. When fitted in this way,

they make a perfectly steam tight joint and add very much to the economical working of the engine.

- 47 *Leaky Pistons.* Leaky pistons are a source of considerable loss of steam and loss of power, because whatever steam flows from one side of the piston to the other is a



Spring Piston Rings. Fig. 193.

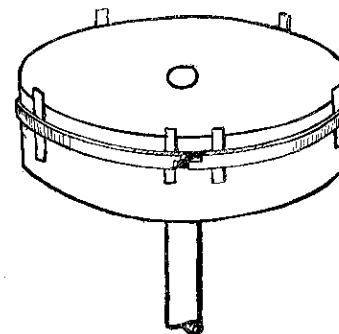
total loss. To determine if piston rings leak all that is necessary to do is to turn the engine a little past centre, block the cross head so that it cannot move, admit steam to the cylinder and then open the cylinder cock at the end of

the cylinder opposite to the end at which steam is admitted; if the rings leak, steam will blow out at this cylinder cock. This method fails, however, if the valve leaks.

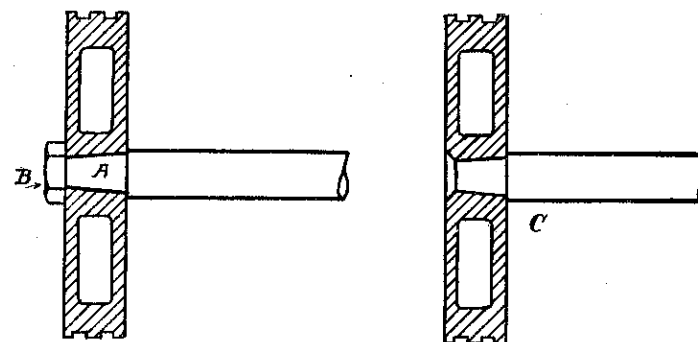
- 48 *Method of Removing Piston Rings.* Whenever it is necessary to remove the piston rings considerable care should be taken not to spring them any more than it is necessary or they will either be broken or stretched past their elastic limit and will never again fit the cylinder properly. An easy method of accomplishing this result is to spring the piston ring out of the groove at the point where the ring is cut, a sufficient distance to insert a thin piece of steel or a piece of stiff tin underneath the ring between it and the piston. By working two or three pieces of tin underneath the ring at three or four places around the circumference of the piston, the ring will be sprung out a sufficient distance to allow it to be slipped out of the groove. These strips may all be inserted at the end of the ring and then slipped around the piston to the proper positions. When the work is done in this way, there is no danger of breaking a ring. See Fig. 194.

- 49 *Piston Rod Fastenings.* Fig. 195 shows two methods of securing the piston head to the rod. As will be noted at A, the head of the piston is bored tapering, and the rod turned to fit this taper, and with a shoulder at the point where the main body of the rod comes up against the piston head. At B, a nut is screwed on the end of the rod, which is sometimes secured after it is screwed in place by means of a pin which passes through both the rod and nut. At C, the rod is simply forced into the piston under heavy pres-

sure and then riveted over. The opposite end of the piston rod is usually screwed into the cross head and locked in place by means of a lock nut or jamb nut.



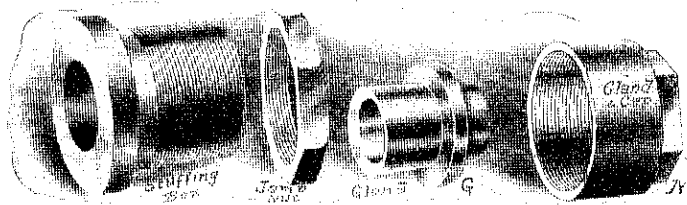
Method of Removing Piston Rings. Fig. 194.



Methods of Securing Piston Heads to Rods. Fig. 195.

- 50 Fig. 196 shows the construction of one style of piston rod stuffing box. The gland G is forced against the pack

ing by means of the nut N, thus pressing the packing tightly against the rod. When adjusted properly, steam cannot blow out past the packing, but drops of water will pass through and show on the piston rod outside of the cylinder. When the packing is new the stuffing box nut



Piston Rod Stuffing Box. Fig. 196.

can be turned up tightly enough by hand to prevent steam from leaking out. If screwed up too tightly, the friction on the rod at this point may be sufficient to reduce the power of the engine a great deal; in fact, many instances

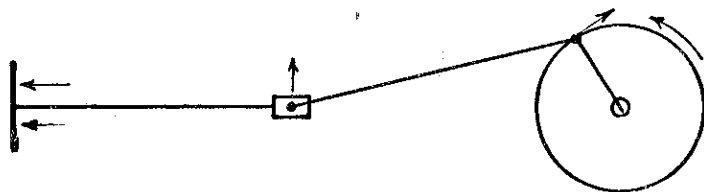


Diagram Showing Pressure on the Upper Guide. Fig. 197.

have been known where engines have been almost stopped by screwing up the stuffing box nut too tightly.

It is always a good plan when an engine shows lack of

power, to examine this point, and see if this nut has not been screwed up too tightly.

- 51 *Pressure on the Guides.* The pressure on the guides of a traction engine, and in fact on all reversible engines, is on one guide when the engine is running in one direction, and on the other guide when the engine is reversed. On referring to Fig. 197, it will be observed that with the position of the piston, connecting rod, and crank as therein shown the line from the piston to the connecting rod and from there to the crank, is a broken one. The force which causes motion comes upon the piston. The crank

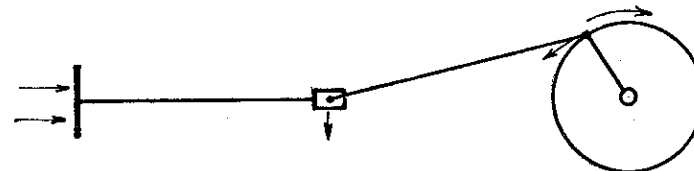


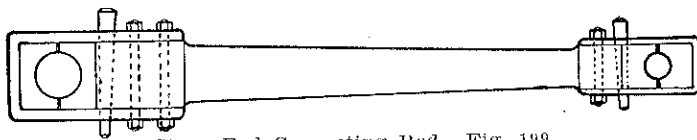
Diagram Showing when Pressure is on Lower Guide. Fig. 198.

which offers resistance is a force acting in the opposite direction. The tendency of these two forces acting upon the ends of this broken line tends to make the line a straight one and causes an upward thrust upon the guides. As long as the engine runs in the direction shown by the arrow the pressure will be on the upper guide. At the end of the stroke this pressure will be zero, and near the middle of the stroke it will be the greatest. Consequently, the guides will have a tendency to wear more in the middle than at either end.

- 52 In Fig. 198 the arrow shows that the engine is running

in the opposite direction. By applying the same principle that we did in the preceding figure, it is evident that all the pressure will come upon the lower guide. In all reversible engines therefore, there must be both an upper and lower guide of equal strength. On an engine that always runs in the same direction the pressure will always be on one guide, but when steam is shut off from the cylinder, and the stored energy in the fly wheel causes the engine to make a few revolutions, the driving force then comes from the crank pin, while the piston acts as resistance; consequently under these conditions the pressure will come upon the opposite guide.

- 53 *The Connecting Rod* connects the cross head with the crank pin, and is the link through which reciprocating motion is transformed into rotary.

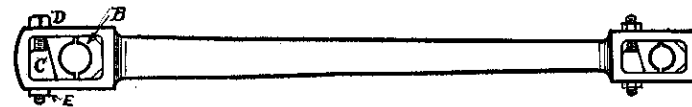


Strap End Connecting Rod. Fig. 199.

- 54 The length of the connecting rod, which is measured from the centre of the crank pin to the centre of the cross head pin, in traction engines, is from four to six times that of the crank.
- 55 Fig. 199 illustrates a well known form of connecting rod fitted with strap and tapered key. It is still used quite extensively on some of the best makes of engines, and when the work of fitting is carefully done there is no question

but that it makes a very satisfactory arrangement; however, there are a large number of joints, comparatively, and these are, as is well known, in all kinds of machinery apt to be a source of trouble.

- 56 The following cut, Fig. 200, illustrates a much simpler form of connecting rod, which is forged out of soft steel; B is the brass crank pin box, one side of which is inclined or wedge shaped. C is an iron wedge block, having one side inclined to correspond with the box B. D is an adjusting screw which passes through a threaded hole in block C, and plain holes in the head of the connecting rod. By turning the adjusting screw the block C can be raised or lowered, thus tightening or loosening the brasses. E is a jamb nut to lock the adjusting screw when the parts are properly adjusted.

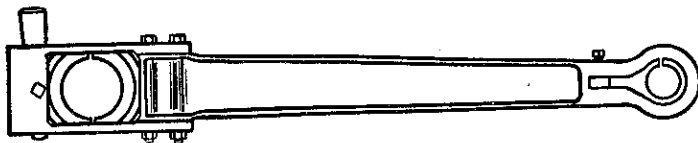


Solid End Connecting Rod. Fig. 200.

- 57 The shape of the body of the connecting rod does not matter much in the case of traction engines. Some are made rectangular and some are channeled. This latter form is for the amount of metal used, the stronger form of the two. See Fig. 201.
- 58 *The Cross Head.* The cross head is a block fastened to the outer end of the piston rod, to which the connecting rod is attached by a pin, sometimes called the wrist pin and

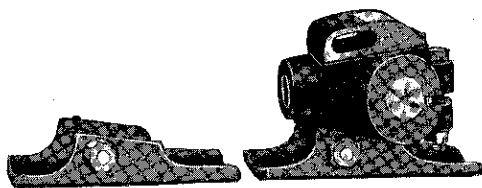
sometimes the cross head pin, passing through the cross head and connecting rod end.

- 59 Nearly all cross heads on bored guide engines follow the same general form of a solid body, having tapered sides, top and bottom, to which shoes are attached, whose inner sides are inclined exactly in the opposite direction to that



Another Style of Connecting Rod. Fig. 201.

of the body, so that when both shoes are in place their upper and lower surface elements will be exactly parallel. By slipping these shoes further up or down the incline, the whole cross head may be narrowed or widened and ad-



Cross Head with Tapered Body and Tapered Shoes. Fig. 202.

justed properly to the width of the guides. The accompanying drawing, Fig. 202, illustrates this type of cross head.

- 60 Another form of cross head that is used on some makes of traction engines has a body with parallel faces and

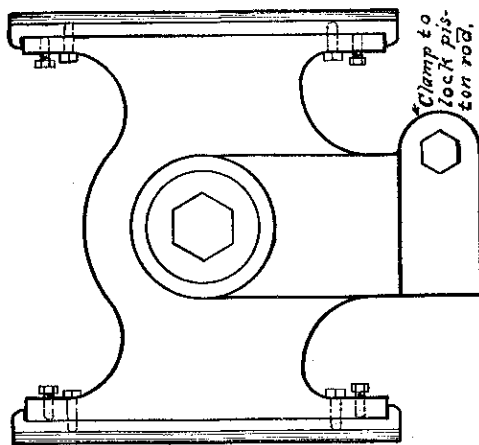
shoes which are adjusted with set screws at each end. See Fig. 203. It is much harder to adjust the shoes in this case, than in the type first described, for, in the former, the upper and lower elements of the shoes cannot be other than parallel, while in the latter, great care must be exercised in adjusting the screws to make them parallel.

- 61 In adjusting the shoes, care must be taken to make the centre of the cross head exactly central with the centre line of the cylinder. In the factory where the work is done with a special jig, the task is easy, but it is harder in the field where there are few tools to work with. A fairly accurate way, however, is to place the engine on the head end centre and connect the cross head to the piston rod, adjusting the shoes so the rod appears to pass exactly central through the stuffing box in the head of the cylinder. For small distances the eye is a very accurate measuring instrument, so that with the exercise of a little care this method may prove quite satisfactory. Fig. 204 represents the cross head used on a locomotive guide engine. When it gets worn it may be re-adjusted by taking out some of the shimming between the parallel bars and the blocks between them. When this is done, care must be taken to re-align the engine.

- 62 *Pounding at the Cross Head.* If the engine runs smoothly when the pressure is on the lower guide, but pounds on the reverse motion, there is very good evidence that the cross head shoes are not properly adjusted. The reason for this pounding is that at the end of the stroke the cross

head falls by its weight and rests upon the lower guide when the engine passes centre, but just as soon as the central point is passed it is thrown forcibly against the upper guide, thus making the disagreeable pounding noise which is heard twice during every revolution.

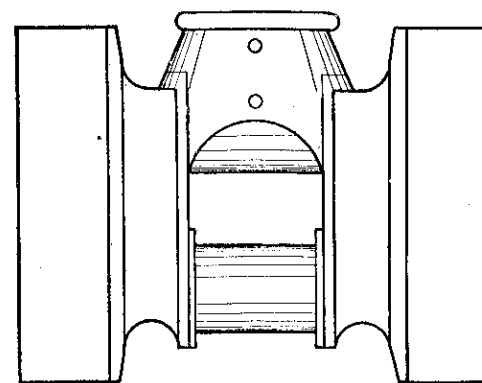
63 *Piston Speed.* The piston speed of traction engines is



Crosshead for Bored Guides. Fig. 203.

from 450 to 500 feet per minute. The piston speed of any engine may easily be determined by multiplying the length of the stroke in feet by the number of revolutions per minute that the engine makes; for example: If the engine has a 14-inch stroke, and runs at 250 revolutions per minute, the piston speed will be $14 \times 200 \times 2$, divided by 12, equals $466 \frac{2}{3}$ feet per minute.

64 *The Crank Disc.* All side crank engines, and this includes nearly all simple engines and tandem compound engines, are provided with a crank disc on the end of the main shaft. This disc is made lighter on the crank pin side than on the opposite side in order to provide a counter balance for the engine. The usual method of accomplishing this result is shown in Fig. 205; the crank disc is bored out a little smaller in diameter than the main shaft and is

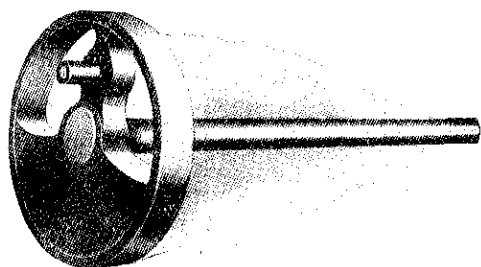


Cross Head for Locomotive Guides. Fig. 204.

then forced onto the shaft by means of hydraulic pressure of a good many tons per square inch. When forced on in this way, there is little danger of its ever becoming loose.

65 *Balancing an Engine.* In a reciprocating engine the piston, piston rod, cross head and connecting rod are constantly moving either forward or backward. Their combined weight amounts to somewhere in the neighborhood

of 150 or 200 pounds, in traction engines, and unless counter balanced in some way, this weight, moving first one way, then another, would cause the whole engine to partake of the same motion, thus making it impossible to hold the engine steady while it is running. The method employed to offset the action of this weight moving backward and forward is to provide an equal weight, or its equivalent, always moving in the opposite direction. This

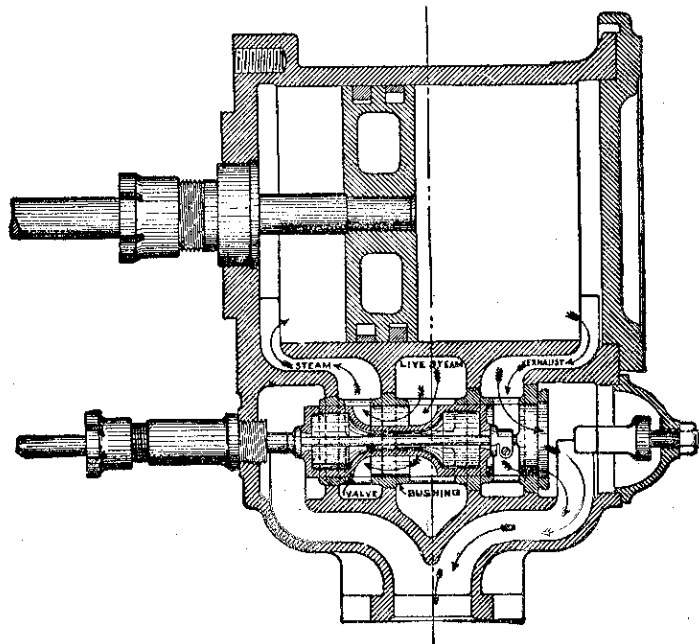


Crank Disc with Heavy Weight Opposite Crank Pin to Balance Engine. Fig. 205.

is accomplished as above indicated, by placing a large amount of weight in the crank disc. It will be observed that when the piston is moving in one direction, this weight which is placed opposite the crank pin is moving about the centre of the shaft in the opposite direction. When the piston, or moving parts, near the end of the stroke, where the shock is the greatest, the weight in the crank disc is exactly opposite and has a tendency to move the engine in the opposite direction. If these two forces are equal, and both act in opposite directions at the same time, they

- will exactly offset each other and the engine will stand still.
- 66 Centre crank engines are provided with heavy weights attached to the main shaft opposite the cranks, which act in exactly the same manner.
- 67 *Valves.* The valves used to admit steam to the cylinders of traction engines may be classified according to form, according to their direction of motion relatively to the piston, and according as they are, or are not, held to their seats by the full pressure of steam in the steam chest.
- 68 Under the first classification we have plain D slide valves, Woolf valves, double ported valves, piston valves, and poppet valves. Under the second classification, balanced valves and unbalanced valves. Both the plain D valves and the Woolf valve have already been explained and need no further mention.
- 69 *Double Ported Valves.* An illustration of a double ported valve appears in figure 182. An examination of the illustration will show that steam not only passes into the steam port in the usual manner, past the outside edges of the valve, but also through a port in the valve itself. The advantage possessed by such an arrangement is that the opening of the port is double the movement of the valve. If the valve moves an eighth of an inch, the port will open one-fourth of an inch. This arrangement has the effect of a quicker acting valve than an ordinary slide valve, and provides for a large volume of steam behind the piston at the beginning of the stroke when it is most needed.
- 70 *Piston Valves.* Piston valves are just like plain D slide valves rolled up into the form of a cylinder. Fig. 206

is an illustration of a valve of this kind. These valves are chilled and made as hard as possible, and then ground to an exact fit in the valve seat, which is also ground to exact



Indirect, Balanced Piston Valve. Fig. 206.

size. Valves made in this style are very satisfactory. Of course, if they wear and leak steam they become practically worthless.

71 *Poppet Valves.* A poppet valve is one that lifts straight

up from its seat by means of a cam and snaps back again under the action of a strong spring. They have been used to a limited extent on some makes of traction engines, but have not come into general use. They are well adapted for slow moving engines, but do not work so well when the speed is high. The advantage possessed by valves of this class lies in the quick opening of the ports and its equally quick closure at cut off, which is much more economical in the use of steam than the slow dragging movement of the slide valve.

72 *A Direct Acting Valve.* A direct acting valve is one that moves toward the right to open the left hand steam port, and toward the left to open the right hand steam port. All of the valves heretofore illustrated have been of this class.

73 A valve which moves toward the left to open the left hand steam port is called an *indirect* valve. See Fig. 206. The majority of traction engines are provided with direct acting valves and only a few have indirect valves. If an indirect valve is used the eccentric is placed 90° minus the angle of advance behind the crank.

74 *Balanced Valves.* If steam is prevented from reaching the back of the valve and exerting pressure thereon, the valve is said to be balanced. There are several schemes for accomplishing this result. One is to insert a ring in a groove in the back of the valve. This ring slides on the inner surface of the steam chest cover, against which it is held by spiral springs in the bottom of the groove. Since it makes a steam tight joint against the cover no

steam can reach the back of the valve within the ring. The portion of the valve not covered by the ring is unbalanced. Sometimes the valves are made semi-circular in cross section and fit inside of a steam tight casing which rests on the edges of the valve seat.

Piston valves are a good example of the balanced type of valve, in fact, they are the most perfectly balanced valves made, since the steam pressure comes equally upon all sides of the valve and do not obstruct its motion in the least.

- 75 *Benefit Derived from Using Balanced Valves.* If the valve is unbalanced it is held to its seat by a considerable force, which increases the total amount of friction between the valve and its seat and makes the valve move much harder. This in turn causes a great deal of friction between the eccentric sheave and strap with a greatly increased tendency to heat at this point. Some of the power of the engine is also absorbed in running the valve, and the eccentric, on account of the load it has to carry, has a tendency to slip.

- 76 The amount of power necessary to run an unbalanced valve is often overestimated. The valve of a certain well known engine, capable of developing 50 horse power, is six inches wide and eight inches long, its area is therefore 48 square inches. If there is a steam pressure in the steam chest of 120 pounds per square inch, the total load on the valve will be 48×120 , or 5,760 pounds. The pressure of the exhaust steam and of the compression may be estimated at 760 pounds at least. The total unbalanced pressure on the valve is, let us say, 5,000 pounds. The force

necessary to pull a smooth valve on a smooth valve seat is usually taken at $1/10$ of the load on the valve. In this case it will require a force of 500 pounds to move the valve backward and forward. If the valve has a total travel of three inches, and the engine makes 250 revolutions per minute, then the valve will move a distance of three inches 500 times in one minute, or a total of 125 feet per minute. The total amount of work required to move the valve will be the force in pounds multiplied by the distance it travels in feet, which in this case is 500×125 , or 62,500 foot pounds per minute. 62,500 divided by 33,000 equals almost 1.9 horse power. Under these conditions 3.8% of the total power of the engine was used in running the valve. If the valve in this case were perfectly balanced, the gain in power would be just 3.8%.

- 77 *Fitting Valves.* The method of fitting slide valves, practiced in the best shops, is to plane both the valve and the valve seat as smooth as possible and then finish both by scraping with a hand scraper to a perfectly flat surface. The planer alone will not make a steam tight joint. Scraping must be done by hand by skilled workmen, and being a long tedious process, is rather expensive. It is very easy to tell if a valve has been scraped by taking it out and looking at it; the short irregular marks of the scraper ought to be plainly visible while the long streaks left by the planer ought not to be. If a valve is not properly fitted, steam will blow through between the valve and its seat into the exhaust and not only cause a loss of steam, but back pressure on the piston.

- 78 *To Determine if a Valve Leaks.* An easy way to do this is to turn the engine until the high part of the eccentric stands vertically. When in this position the valve is exactly in the middle of its travel and covers both ports. If the cylinder cocks be opened and steam turned into the steam chest, none will get into the cylinder, and none can pass out through the cylinder cocks unless the valve leaks.
- 79 *The Throttle Valve* is placed on the main steam pipe somewhere between the governor and the point where the steam pipe enters the boiler and is operated by a rod and lever on the engineer's platform. Some throttle valves are made much like an ordinary gate valve and others consist of a conical plug having an opening through it which turns half way around to admit steam.
- 80 All engines should be provided with a cut off valve of some sort, between the throttle valve and the boiler which may be closed whenever it becomes necessary to repack the throttle valve stem or to make repairs.

QUESTIONS FOR PART IX.

1. Explain the arrangement of cylinders in each of the following engines: (a) a duplex engine, (b) a tandem compound engine, (c) a cross compound engine.
2. Why are the cylinders of a compound engine made of different sizes?
3. Describe the course of steam through the cylinders of a tandem compound engine.
4. Is there any back pressure on the high pressure piston of a compound engine; explain?
5. How may tandem compound engines be classified?
6. How is the centre head of a Woolf compound engine made steam tight?
7. What is cylinder condensation?
8. Why is dry steam desirable in an engine cylinder?
9. What means are adopted in traction engine design to secure dry steam?
10. Explain the effect of jacketing the cylinder with live steam.
11. What is superheating, and how is it done; is it an advantage?
12. Explain the effect of cushioning the exhaust.
13. What advantages are gained by compounding?
14. Can a cross compound engine stop on dead centre?
15. Explain the use of an intercepting valve.
16. What is clearance and why should the clearance volume be made small?

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17. Explain the construction of an engine cylinder.
18. What two types of guides are used on traction engines?
19. What is a side crank engine, (b) a centre crank engine?
20. What are piston rings made of and how are they fitted?
21. Explain how to find out if a piston leaks.
22. How may piston rings be removed?
23. Show by diagram why the pressure of the cross head upon the guides changes when an engine is reversed.
24. What causes pounding of the cross head?
25. What is the usual piston speed of traction engines?
26. How is an engine balanced, and why is this necessary?
27. How may valves be classified?
28. What is a balanced valve; how are valves balanced?
29. What is an indirect valve?
30. How are valves fitted?
31. Explain how to determine if a valve leaks.

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SPEED CONTROL

PART X

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LESSON X.

GOVERNORS.

1. *Introduction.* Neither the load that is on the engine nor the force that drives the piston are constant, but on the contrary both vary from instant to instant. In traction engines especially the load is very variable, one moment taking the full power of the engine, as when a wet bundle goes into the separator, and the next requiring almost no power, as when the separator is running empty. The pressure of the steam on the piston is also variable, being highest at the beginning of the stroke and gradually falling off after cut-off occurs until it is perhaps almost nothing at the end of the stroke. The turning effort on the crank is also variable, being nothing at the ends of the stroke and greatest at the point where the crank and connecting rod make a right angle with each other.
2. In order to have an engine run steady it is necessary to proportion the average force acting on the piston to exactly meet these variable resistances by some automatic device that will act quickly and with certainty.
3. *Methods of Governing.* It is evident that the effective force driving the piston can be varied in any of the three following ways: by changing the pressure of steam, by changing the quantity of steam admitted to the cylinder and by varying the back pressure.

4 Governors which influence the *pressure* of the steam are called *throttling* governors, and are placed on the main steam pipe. As the name indicates, they decrease or increase the opening through which the steam flows from the boiler to the engine, according as the speed of the engine increases or decreases. If the speed of the engine increases beyond a certain point a valve partly closes the supply pipe, causing the steam to pass through a small opening, and since not enough is admitted to the steam chest to keep it filled with steam at boiler pressure, it must expand to a lower pressure and is admitted to the cylinder at a low pressure.

5 In all high-speed steam engines those governors which vary the quantity of steam admitted to the cylinder without changing its pressure are placed on the main shaft and act directly upon the eccentric. Governors of this class are called *shaft governors* and an engine thus equipped is called an *automatic engine*. The action of the shaft governor is to cause the steam to be cut off earlier in the stroke to correspond with the changes of the load on the engine. If the load is light, cut-off occurs early, and if the load is heavy the cut-off occurs later. Thus the average pressure driving the piston is decreased or increased in accordance with the load. The shaft governors act in one of two ways: either the eccentric is rolled farther around the shaft and given a greater angle of advance, or it is moved across the shaft and the travel of the valve shortened. In the first case the valve is given more lead, an earlier cut-off, earlier release and earlier compression when the load becomes lighter; in the second method the effect is also to increase the angle

of advance, to make cut-off, release and compression occur earlier, but the lead remains constant. Shaft governors are not used on traction engines for the reason that they are not well adapted to a reversible engine. They are somewhat more economical in the use of steam than throttle governors and are used largely on stationary engines.

6 There are no governors designed to act primarily on the exhaust and increase or decrease the back pressure, for the reason that they would not be economical in the use of fuel and water. Incidentally, however, the effect of shaft governors is to vary the point of compression and thus vary the back pressure to some extent.

7 Corliss engines are governed by changing the point of cut-off, but the governor is not placed on the main shaft, neither does it vary the position of the eccentric. It is driven from the main shaft, however, and acts on a releasing gear mechanism which trips and shuts off steam at the desired point.

8 Locomotives and traction engines running with the governor belt off are governed by hand in two ways: by the throttle, and by "hooking up" the reverse lever. The effect of "hooking up" is to vary the point of cut-off; working the throttle governs the pressure of steam in the cylinder.

9 *The Effect of the Throttle Governor* on the pressure in the cylinder under the different conditions as to load is shown graphically in Fig. 207.

Since this style of governor does not act upon the valve, the point of cut-off will remain at some fixed point; in the

diagram this point is supposed to be at half stroke. When the engine is working under full load the pressure behind the piston is shown in the outer diagram; up to cut-off the pressure behind the piston is almost equal to boiler pressure, but from that point to the end of the stroke it gradually falls. Under half load the size of the opening in the steam pipe is reduced so that less steam can pass through, with the result that a good deal of expansion and drop of pres-

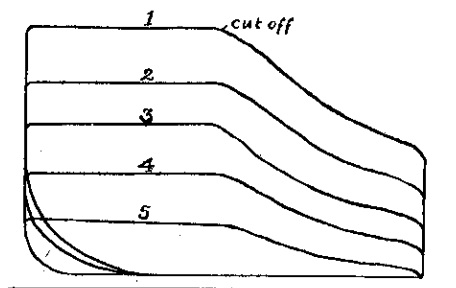


Diagram Showing the Effect of a Throttle Governor on Steam Pressures Under Varying Loads. Fig. 207.

sure takes place in the steam chest. The pressure behind the piston for half load is represented by line number 2, in the diagram. The lighter the load on the engine the lower the pressure on the piston will be, as shown by lines 3, 4 and 5. Line 5 represents the engine running light; almost no steam passes through the steam pipe and the pressure behind the piston is just sufficient to overcome the friction of the engine itself. In each case the pressures at different parts of the stroke are proportional to the length

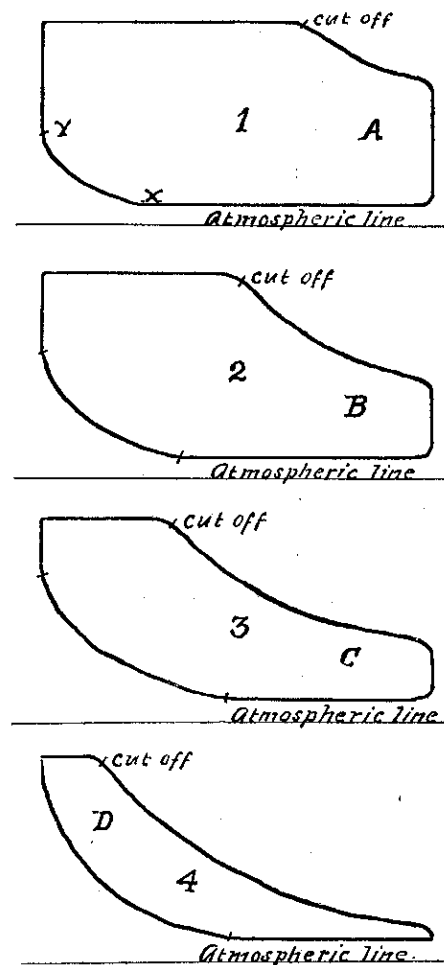


Diagram Showing Effect of Shaft Governor on Steam Pressures Under Varying Loads. Fig. 208.

of vertical lines extending between the lower line of the diagram and whichever one of the numbered lines is under consideration.

10 *Governing by Changing the Point of Cut-Off* is made the subject of diagrammatic analysis in figure 208. The height of each one of the diagrams, 1, 2, 3 and 4, up to the point of cut-off is the same, but the point of cut-off in each is different, to correspond to the difference in load. Since the height of the diagram represents to some scale the pressure behind the piston, it is clear that steam is admitted to the cylinder at the same pressure in each case. After cut-off the pressure falls as shown by the expansion lines. When the load is light cut-off occurs sooner, the expansion drops lower, and the total average pressure driving the piston is less than for heavy loads.

11 The lower line is the exhaust line, and since it is at some little distance above the atmospheric line, it shows that the piston is meeting with some resistance on the backward stroke. In diagram A, where the engine is working under a heavy load, the exhaust closes at X, and the steam remaining in the cylinder is compressed as shown by the line X Y. Under a lighter load, where the cut-off occurs earlier, the valve cuts the steam off earlier in the stroke and the compression rises still higher. This is because the governor gives the eccentric a greater angle of advance, which, with a slide valve, makes all of the events in the distribution of the steam occur earlier in the stroke.

12 Under a very light load, as shown in diagram D, the steam is compressed on the backward stroke until it is fully

as high as boiler pressure. This, of course, causes the piston to do an extra amount of work on the back stroke and so tends to reduce the speed of the engine. It is in this way that engines are, as previously stated, governed to some extent by the regulation of compression.

13 *Governing the Speed by Hand.* All reversible engines that are provided with a notched reverse lever quadrant can be governed by hand within certain limits as to load by moving the reverse lever nearer to the centre notch. The effect of so doing is to decrease the throw of the eccentric, so that the valve does not open the ports as wide, and to give it a greater angle of advance, which, as before explained, causes steam to cut off earlier in the stroke. It must be understood that the eccentric is not actually moved on the shaft to make the angle of advance any greater or less, but the effect of moving the reverse lever is the same as though the angle of advance were changed. A further discussion of this interesting topic will be taken up in Lesson XII.

14 The opening or closing of the throttle will also control the speed of the engine by changing the pressure behind the piston. A good traction engineer makes a great deal of use of the throttle in controlling the speed of his engine on the road and in moving into position. Slowing down the speed by partly closing the throttle gives him time to work the steering wheel, and in putting on the belt he opens the throttle very slowly in order to start slowly without throwing the belt.

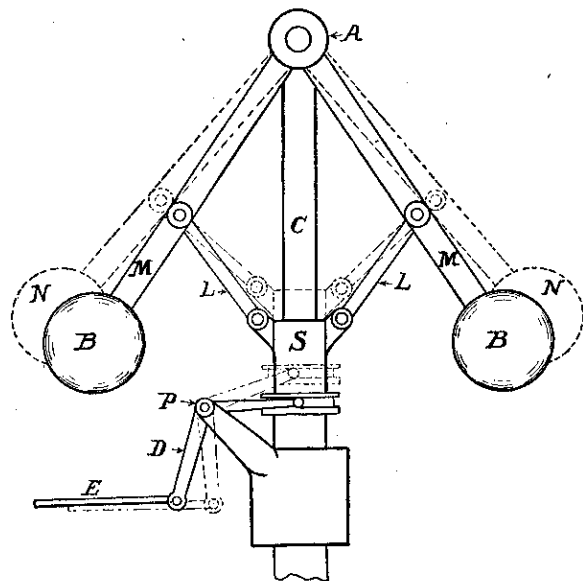
15 *Governing Effect of the Fly Wheel.* The governor, no matter how well constructed, can not take care of all the

small irregularities in the speed of the engine during a single revolution of the shaft or of two or three revolutions. The crank is supposed to revolve at a uniform rate of speed and not to vary more than two or three per cent either way from the speed required. If the turning force at the crank were constant the task of governing would be easy, but it is not constant; at the beginning of the stroke it is nothing, but increases gradually toward the middle and from there drops to nothing at the other end of the stroke.

- 16 The resistance at the pulley rim in pulling a heavy load is constant; hence we have the condition of an intermittent or pulsating force acting against a constant resistance. The average amount of this force must be equal to the resistance or the speed will fall. It is necessary, therefore, to provide some device that will store up energy when the piston is in the middle of its travel and give it up when the crank passes centre. This is the duty of the fly wheel. The heavy rim of the fly wheel, at a distance from the centre of the shaft, resists the heavy push of the piston at the middle of the stroke so much that the speed of the engine is not perceptibly increased, and at the end of the stroke when the crank receives no help from the piston the *inertia* or energy that is in the fly wheel causes it to give up enough force to enable the crank to pass centre without any change of speed. A single-cylinder engine could not run without a fly wheel, but would stop on centre. If the fly wheel is too small and light the engine will not run steady. The larger in diameter the fly wheel is, and the more metal there is in the rim, the less change there will be in its speed during a single revolution.

- 17 Gas engines require very heavy fly wheels because ordinarily they receive only one impulse during every four strokes of the piston, and unless the fly wheel were heavy enough to absorb the power during explosion and give it up on the succeeding strokes the engine would have a very irregular speed. Large fly wheels do not add power to an engine, but they cause it to have a steadier motion.
- 18 *Centrifugal Force.* If a body be made to revolve rapidly about a centre, every particle of that body has a tendency to fly outward from the centre; the faster the body revolves the stronger this tendency becomes, and if the speed becomes great enough the force will be sufficient to burst the body in many pieces. This force is called *centrifugal force*. If the governor belt should fly off and there was not much load on the engine it would very quickly develop speed enough to burst the fly wheel. Many such accidents have occurred which have not only wrecked the machine but have also killed people in the immediate vicinity. Grindstones and emery wheels often burst also on account of centrifugal force when run at too high a speed.
- 19 Centrifugal force, however, may be, and is, taken advantage of very often to produce most useful results. It is the principle upon which most all steam engine governors work. Its method of application will now be considered.
- 20 *Watt's Governor.* The simplest form of governor, and the one invented by Watt, is shown in figure 209. It consists of two balls B, having arms pivoted at A, and two links L attached by pins to a sliding sleeve S. A bell crank lever D, pivoted at P, is actuated by the sleeve S, as shown

in the figure. Rod E is attached to the throttle valve. A pulley, not shown in the drawing, is driven by means of a belt from the main shaft, and causes the spindle C and the balls B to revolve at a rate exactly proportional to the rotation of the main shaft. The balls, under the action of



Watt's Governor. Fig. 209.

centrifugal force, tend to move farther away from the point of support A, but being held by the arms M, are obliged to travel in the arc of a circle about A as a centre.

- 21 When the engine is at rest the balls occupy the lowest

position and the throttle valve is wide open. When they are in motion they take up some other position, such as N; this lifts the sleeve S and rod E moves toward the right, partly closing the throttle valve. This form of governor depends upon the action of gravity to bring the balls down and upon centrifugal force to raise them. It has certain defects and is not used at the present time, except in a modified form for slow-speed engines of the Corliss type.

- 22 Governors are designed in such a way that the movement of the sleeve from its bottom to its top position will take place within a certain range of speed of the balls. A certain speed of rotation must be reached before the balls move outward and act on the valve. When this speed is reached the governor begins to act. If the governor reaches its top position when the speed increases, before it closes the steam supply to the engine, then the speed may go on increasing indefinitely because the governor no longer acts as a governor. It governs only through the range of speed necessary for the sleeve to rise from its bottom to its top position, or from the top to the bottom position if the valve spindle moves down to shut off the steam.

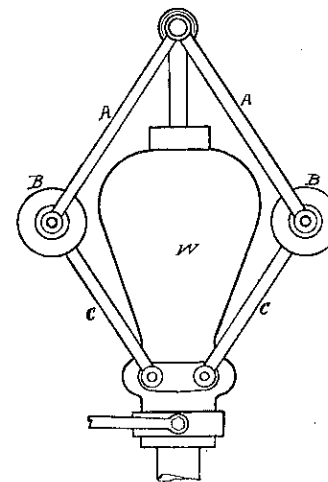
- 23 *Defects of Watt's Governor.* The governor balls must rise or fall in order to close or open the throttle valve; but since their position depends upon the speed of the engine, it is clear that the engine must change its speed before the governor can act. When the engine is running light the throttle valve must be almost closed, admitting only enough steam to overcome the friction of the engine. In this case the balls must swing much farther outward than when the

engine is heavily loaded and the throttle is wide open. Evidently, then, the engine must run somewhat faster, running light, in order to revolve the governor balls faster and make them swing farther out than when running loaded. Thus it will be seen that the speed of the engine can not be constant for varying loads, but must change with every change of load. This is also true of the other governors, because all governors act only *after* the engine has changed its speed, but the variation in speed with other forms of governors is much less. An examination of figure 209 will reveal the fact that in order to move the rod E, which operates the throttle valve, an appreciable amount, the balls must move through a considerable distance, and in order to do so there must be a considerable variation in speed, especially at the *higher speeds*. Consequently this governor is of no use for engines that run at high speeds, such as traction engines. Furthermore, gravity is depended upon to pull the balls down after they have been raised by centrifugal action. But gravity acts slowly in such a case because of the resistance of the throttle and the tendency of the balls, on account of their motion, to keep revolving at the same rate of speed and in the same plane of revolution.

- 24 The *Weighted Governor*, also known as Porter's governor, while not used on traction engines, is of interest in general discussions of governors, because it is an example of how the *sensitiveness* of the governor may be increased. The term "sensitiveness," as used in this connection, means susceptibility to slight changes in speed, and its power to keep the speed of the engine nearly uniform.

SPEED CONTROL

- 25 Figure 210 shows this style of governor. The balls B are made small and are revolved at a high rate of speed. Rods A are attached to the spindle and rods C, to a weight W, which is free to move up or down on the spindle, but which revolves with it. When the balls move upward and outward under the action of centrifugal force they must



The Weighted Governor. Fig. 210.

- also lift the weight W as well as move the throttle. The lever which moves the throttle is counterbalanced also and moves easily.
- 26 The effect of this arrangement is that a comparatively slight movement of the balls, owing to the way rods A are arranged, moves the throttle a considerable amount and

hence a slight change in speed will affect the governor. The weight *W*, not being affected by centrifugal force, and being quite heavy, acts promptly to draw the valve down and open the port wider.

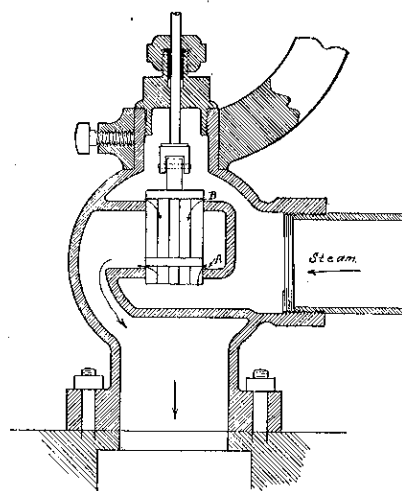
27 *Traction Engine Governors.* The governors used on traction engines are all of the type known as *spring loaded* throttle governors. Instead of being provided with a weight to bring the balls back to place they are provided with a spring that resists centrifugal force and whose *resistance increases* somewhat faster than the centrifugal force does. The result of such an arrangement is to prevent violent fluctuations in the pressure of steam in the cylinder and to keep the speed of the engine within narrow limits.

28 *Hunting of the Governor.* When a governor is too sensitive to changes in the load on the engine, and either opens the port wide or closes it almost entirely, it is said to "hunt" and is not as satisfactory as one that acts more slowly. This is why the resistance of the spring in spring-loaded governors is made to increase faster than centrifugal force, and why governors like those of the Porter type are provided with a *dash pot* to offer resistance to any sudden movement of the governor spindle.

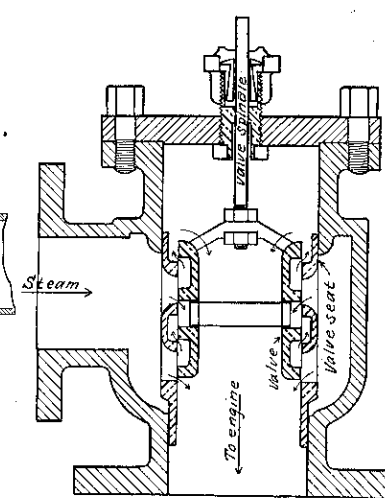
29 *Throttle Governor Bodies and Valves.* Figures 211 and 212 represent two different methods of constructing the body and valve of throttle governors. Two objects are aimed at: one is to provide the largest possible opening or closing of the steam passages with the least movement of the valve, because the movement is slight at best; and the other is to make the valve balanced, that is, subject to as

much pressure on the top as it is on the bottom in order that the governor will not have any steam pressure to overcome in moving the valve.

30 In figure 211 this is accomplished by making the valve in the form of a spool which seats at A and B. The steam passages are cored out in such a manner that steam comes upon the top side of the upper flange and upon the bottom of the lower. The upper flange is a trifle larger and so



Governor Body and Valve.
Fig. 211.



Governor Body and Valve.
Fig. 212.

bears a little more pressure than the lower one, thus throwing the valve slightly out of balance. In figure 212 the valve is made hollow and is therefore balanced; steam enters the

steam chest at four places, as shown by the arrows, thus making it a quadruple-ported valve. 1-32 of an inch of movement of the valve stem provides for $\frac{1}{8}$ of an inch of steam port opening, thus helping to make the governor more sensitive to small variations in the speed of the engine without increasing its tendency to "hunt."

31 *Regulating the Speed of an Engine with Throttle Governors.* Throttle governors, as before explained, govern well only within certain limits of speed for which they are designed. Their normal rate of speed is usually stamped somewhere on the governor. When a traction engine is sent out the pulleys on the engine shaft and on the governor are made the right size to give the governor the correct speed for the normal speed of the engine. Within certain limits the speed of the engine may be changed by changing the tension of the speeder springs, or by changing the position of the valve by adjusting the nuts on the top of the spindle, thus changing the position of the valve in the governor body.

32 The first method changes the load on the valve and makes a change of speed necessary to change the centrifugal force and cause the governor to act. The second method varies the travel of the governor valve. In either case a considerable change in speed can not be accomplished without changing the power of the engine. This is especially true of the second method, which, while it makes a slow speed possible, does so by preventing the steam pressure in the cylinder from approaching anywhere near boiler pressure, consequently decreasing the power of the engine.

33 If it is found necessary to change the speed of the engine very much, and for a considerable length of time, it can be done better by changing the size of the pulley on the governor shaft, making it the right size to run the governor at its normal rate of speed. The following rules explain how to figure the sizes of pulleys:

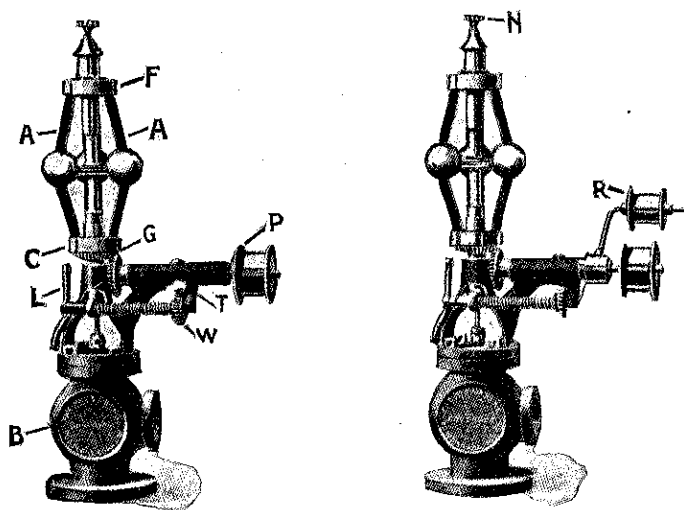
34 *Rule One. To find the Diameter of the Governor Shaft Pulleys:* Multiply the desired number of revolutions of the engine per minute by the diameter in inches of the engine shaft pulley, and divide by the speed stamped on the governor; the quotient will be the diameter of governor pulley needed.

35 *Rule Two. To Find the Diameter of the Engine Shaft Pulley:* Multiply the number of revolutions stamped on the governor by the diameter of the governor pulley in inches, and divide by the speed at which the engine is to run; the quotient is the diameter in inches of the engine shaft pulley.

36 In general it is better to change the governor pulley, but if the change in the speed desired would make it too small, then Rule Two must be used to determine what change to make in the engine pulley.

37 *The Pickering Governor*, which is made the subject of illustration in figure 213, is a style of governor that is used widely on traction engines. The balls are made light and revolve at a high rate of speed, ranging between 400 and 500 revolutions per minute for traction engines. Motion is given to the balls by means of a pair of bevel gears G, which are driven by means of a belt from the engine shaft. The pulley P on the governor is made enough smaller than the

pulley on the engine shaft to give the governor balls the correct speed. When the balls are rotated they tend to move outward under the action of centrifugal force, and downward because the lower connection is fixed in position and the upper one, F, is free to move. The throttle valve in the body B is closed by moving downward. The arms A are made of a number of thin leaf springs fastened rigidly to



The Pickering Governor. Fig. 213.

the heads C and F and to the balls, thus avoiding the wear and lost motion due to pin joints. The spring arms are made stiff and strong and resist the outward movement due to centrifugal force. When the engine begins to slow down

on account of a heavy load the spring arms bring the balls quickly back toward the spindle, thus raising the valve and letting in more steam.

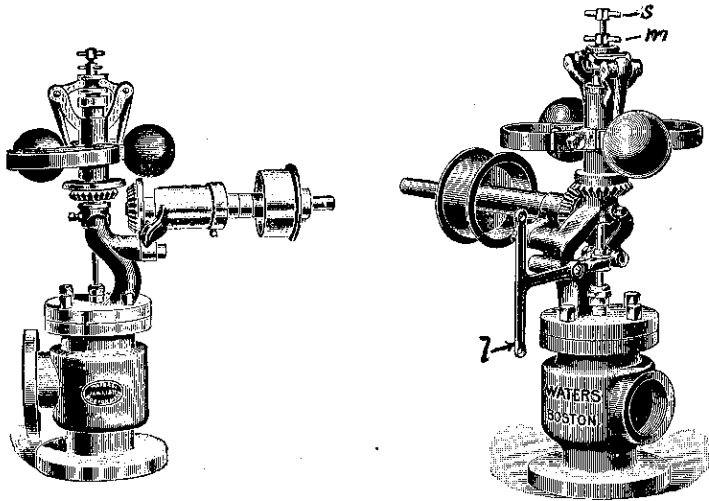
38 *Changing the Speed.* This may be done by giving the speeder spring a little more tension. There is a worm wheel W on the outer end of this spring, operated by means of a thumbscrew T. By turning this screw toward the right the spring is tightened and a forked arm which engages a collar on the valve spindle holds the latter firmly up to its seat and puts a load on the valve which has the effect of holding it open or bringing it back to its original position when the speed of rotation of the balls decreases.

39 *The Sawyer's Lever* is shown at L. Two wires or cords run from either end of this lever to the engineer's platform, enabling him to close the governor valve and change the speed of his engine at will. This lever derives its name from the fact that it was operated in sawmills by the head sawyer to increase the speed of the engine when sawing a large or especially difficult log.

40 The later governors of this type are provided with a knurled nut N, whose lower end rests against the top of the valve spindle and changes the position of the valve as well as its vertical movement. This gives the governor a wider variation in speed.

41 *The Safety Stop*, with which some of these governors are provided, consists of a heavy pulley R, which rests, normally, on the top of the governor belt. If the belt breaks, this pulley falls and, acting in the same way as the sawyer's lever, forces the valve to its seat and stops the engine.

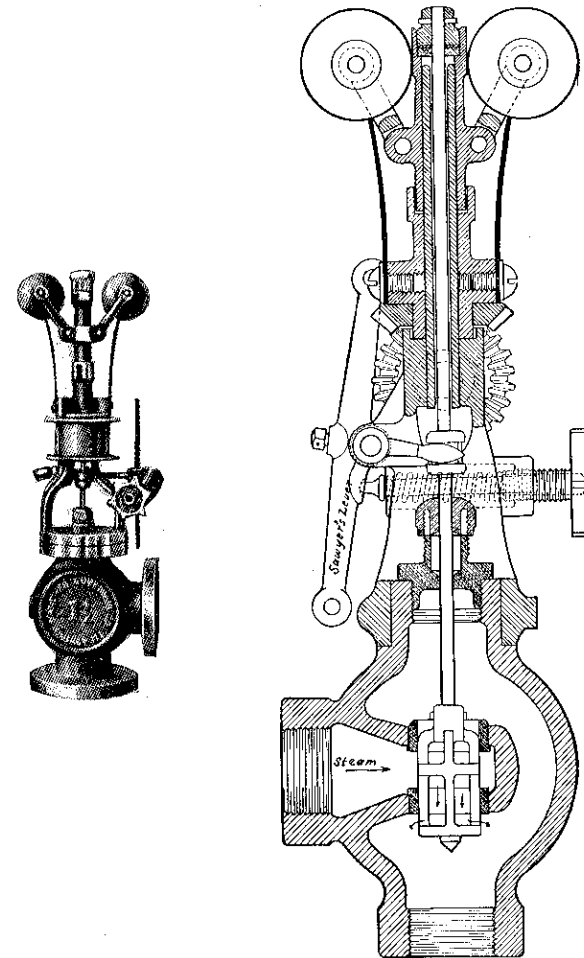
- 42 *The Waters Governor* is also a high-speed governor. Like all modern high-speed throttle governors, it does not depend upon the action of gravity but upon centrifugal force and the action of the springs which are attached to the spindle and to the balls. The former throws the balls outward, the



The Waters Governor. Fig. 214.

latter tends to hold the balls close to the spindle and resists centrifugal action. See Fig. 214.

- 43 *Changing the Speed.* This governor is also provided with a sawyer's lever, as shown at I in the figure, for controlling the speed of the engine from the engineer's platform. The speed at which the engine runs can be adjusted permanently



The Gardner Governor. Fig. 215.

by means of the screw *s*. Screwing this *down decreases* the speed of the engine; screwing it *up increases* the speed. If this screw is lowered as far as it will go, the valve in the governor body will be closed and the engine can not run. After adjusting to the proper speed the jamb nut *m* should be screwed down, locking the adjusting screw in place.

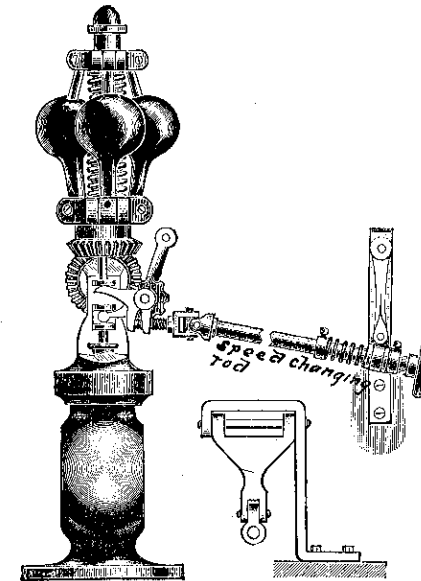
44 *The Safety Stop.* The action of this device on the Waters governor is shown at the left in figure 214. A spring acting on the gear shaft throws the gears out of mesh when the belt breaks and allows the whole top part of the governor to fall and close the valve. In putting the governor in operation again the top part must be raised, the set-screw in the collar on the gear shaft pointed directly toward the engine shaft, and the gear slipped into mesh. The tension of the governor belt will hold the gears in mesh.

45 *The Gardner Governor* of the style most frequently used on traction engines is illustrated in section in figure 215. It is equipped with a safety stop if desired, and with a sawyer's lever and speeder, the two latter being plainly visible in the diagram.

46 *The Eclipse Governor* is another type of throttle governor used on a large number of traction engines. It is provided with a strong compression spring surrounding the spindle, which brings the balls back to their position of rest. The details of construction are clearly shown in the accompanying cut, figure 216. This governor is fitted with a speeder spring, a sawyer's lever and a speeder rod extension to the engineer's platform for changing the speed of the engine.

47 *Horizontal Governors.* Each of the different makes of

governors just described are made in either the vertical or horizontal style. When made horizontal the driving pulley is placed at the base of the spindle, as in figure 217. Some builders of traction engines prefer a horizontal governor,



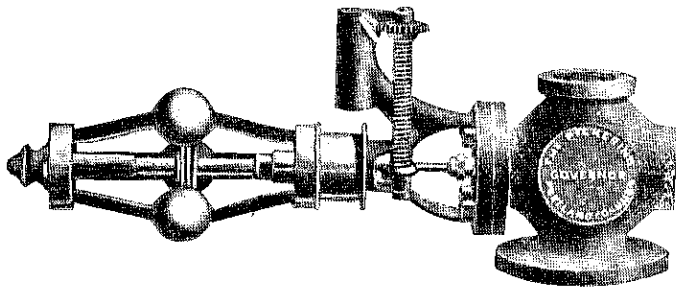
The Eclipse Governor. Fig. 216.

claiming that it is less influenced by jolting over rough roads than the vertical governor, and so maintains a more even speed of the engine on the road.

48 *The Care of Governors.* They should be kept clean and

all the boxes should be kept oiled with a good grade of oil that will not gum. In case they do become gummy they may be cleaned with kerosene.

- 49 The valve spindle stuffing box should be packed with candle wicking which has first been braided and given a coat of oil and graphite. The packing nut can be screwed down tightly enough by hand. It ought to be quite loose, so that drops of water may come through but no steam. If screwed on too tightly the governor will stick and the speed



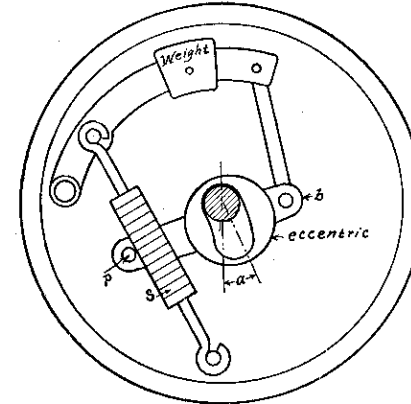
A Horizontal Governor. Fig. 217.

of the engine will be irregular. Sometimes a drop of paint will be found on the valve stem of a new governor which will make it stick, or the valve stem may become slightly bent. This often happens if the governor is removed from the engine; the stem is made of a small brass rod and if the governor is not lifted off perfectly straight it is sure to get bent.

- 50 *Irregularities in the Speed of the Engine* should always be looked after in the governor first. If the speed is some-

SPEED CONTROL

times too fast and at other times too slow it is probable that the governor valve sticks, that the stem is crooked, the packing too tight or that the belt slips.



A Simple Shaft Governor. Fig. 218.

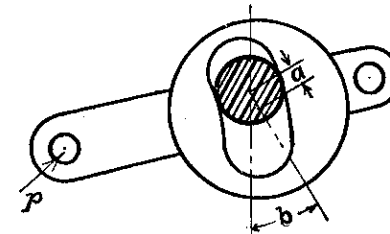


Figure 219.

- 51 If the engine races it may be caused by a loose belt, a loose pulley, a loose gear on the governor, too much friction

on the governor shaft, oil on the belt, or else some one has adjusted the governor for a very high speed.

- 52 *A Shaft Governor.* A simple form of shaft governor is shown in figure 218. The engine is supposed to be at rest and on dead centre with the crank on the left side of the shaft. When in this position the eccentric has a certain angle of advance a , and it is in position to give the valve full travel. When the engine starts it has to attain a certain speed before the weights develop enough centrifugal force to overcome the tension on the spring s . When this speed is reached the weights move outward and the arm b , which is pivoted at p , carries the eccentric across the shaft. The effect of this is to bring the centre of the eccentric nearer to the centre of the shaft as shown in figure 219.

- 53 When this occurs the valve travel is reduced. In the figure it is only equal to a and the angle of advance is increased to b . In extreme cases of high speed the valve travel is little more than the amount of lead. With a governor constructed like the one under discussion the lead of the valve increases as the speed of the engine increases.

- 54 The method of changing the speed of a shaft governor engine is to change the tension on the springs and shift the position of the weights.

- 55 To increase the speed of the engine move the weight nearer to the pivot on which the weight arm turns and increase the tension of the spring; to make the engine run slower move the weight farther out and slacken the tension on the spring. It is impossible to change the speed while the engine is running.

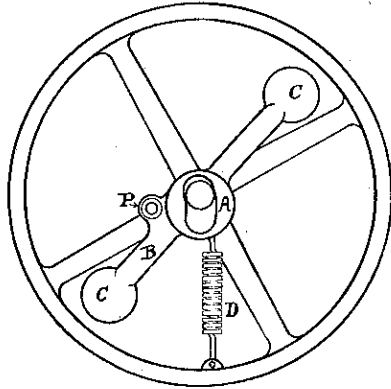
- 56 *The Inertia Shaft Governor.* In this type of governor the eccentric is moved across the shaft partly by centrifugal force and partly by that property of the weights which is called *inertia*.

- 57 *Inertia* is that property of a body by virtue of which, when once put in motion, it has a tendency to keep in motion, or, if in a state of rest, to remain at rest. There are many examples of inertia; for example, if a ball is thrown it will keep on moving unless some external force stops it. The force to do this in the case of the ball is the resistance of the air and gravity. If a railroad car on a level track be put in motion it will keep on moving until the friction of the wheels on the rails or some other external force makes it stop. It always requires a great deal more force to start a load than it takes to keep it in motion after it has once started. The reason for this is that the inertia of the load resists the force causing motion. Many other examples of inertia might be furnished, but these will readily occur to the reader after he gives the matter a little thought. The principle of inertia is taken advantage of in the type of governor shown in figure 220, the construction of which is as follows:

- 58 A is the eccentric, which is slotted and fits loosely on the shaft. B is a rod attached to the eccentric, having balls C attached to each end; a helical spring D is fastened to the eccentric at one end and the other is attached to a boss cast in the rim of the fly wheel.

- 59 From what has been said in regard to inertia it is evident that if the fly wheel should move ahead suddenly the bar B

would remain at rest, that is, it would not turn with the wheel until the tension on the spring becomes great enough to overcome the inertia and cause it to rotate with the wheel.



The Inertia Governor. Fig. 220.
The wheel rotates in the same direction as the hands of a watch.

- 60 Engines of this class are not started suddenly as a rule, but on the contrary quite slowly, and the tension on the spring is sufficient to start the arm with the wheel. The valve will now have full travel and its latest point of cut-off, giving the engine plenty of steam and increasing its speed. When the engine nears full speed its increase in speed becomes more rapid and the original tension on the spring D becomes insufficient to overcome the inertia of the arm and balls. Consequently they lag behind the wheel and the centre of the shaft moves farther down in the slot of the eccentric, thus bringing the centre of the shaft nearer

to the centre of the eccentric. The effect of this action is to shorten the throw of the eccentric and to increase its angle of advance, making the valve have less travel and causing cut-off to occur earlier in the stroke and slackening the speed of the engine.

- 61 After the engine attains full speed, if its speed should slacken in the least, the arm and balls would move faster than the wheel and push the eccentric across the shaft nearly to the position shown in the drawing. This would cause cut-off to occur earlier and give the engine more speed, until the arm again changes its position relative to the wheel and adjusts the point of cut-off relatively to the load.
- 62 In order to adjust the speed of an engine provided with an inertia governor, the best way is to add to or take from the weights at the ends of the arms, until the speed is nearly correct and then make the final adjustment by changing the tension on the spring. The ends of the arm are sometimes cast hollow and filled with shot and sometimes composed of a number of discs held in place with a bolt in order to make it easy to adjust the weights.

QUESTIONS FOR PART TEN.

1. In how many, and in what ways may an engine be governed?
2. In what way does a throttle governor act?
3. Show by means of a diagram the effect of a throttle governor, (a) when the engine is heavily loaded; (b) when running with no load.
4. Show by means of a diagram the effect of a shaft governor on the steam pressure in the cylinder, (a) when running with a heavy load, (b) when running with a medium load, (c) with no load.
5. In what way may a traction engine be governed by hand?
6. Explain the governing effect of the fly wheel. Why do some engines require a heavier fly wheel than others?
7. What is centrifugal force?
8. Mention some of the defects of the Watt's type of governor.
9. Explain the term "sensitiveness" as applied to a governor.
10. What type of governor is used for traction engines?
11. What is meant by the term "hunting of the governor?"
12. What two objects are aimed at in the design of throttle governor valves?
13. In what three ways may the speed of an engine be changed with a throttle governor?

14. In case a considerable change in the speed is desired, how may it be secured?
15. What is the use of the Sawyer's lever?
16. How does the safety stop on the Pickering governor act?
17. How do you change the speed of a Water's governor?
18. How should governors be cared for?
19. If an engine races, what is probably the cause?
20. What will cause the speed of an engine to be irregular?
21. Explain the action of a shaft governor.
22. How is the speed of an engine provided with a shaft governor changed?
23. Define inertia and give an example.
24. How do you change the speed of an engine fitted with an inertia governor?

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PART XI

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LESSON WITH QUESTIONS

ENGINE MANAGEMENT

PART XI

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

LESSON XI.

ENGINE MANAGEMENT.

1. *Directions for Starting an Engine.* An engineer should adopt a regular order in starting or stopping an engine, and then stick to it. Every move then will come to be a habit and there is less danger of omitting any important detail. The following outline is a good one to follow in starting a traction engine, and with a few modifications will do for stationary engines as well:

1. Look over the machine and see that everything is in proper order.
2. Make sure that the cylinder cocks are open.
3. The crank should make an angle of 45° with the centre line of the engine, and be leaning toward the cylinder and moving from it, to start easily.
4. Open the throttle a small amount to warm the cylinder and drive the water out of the pipes.
5. Fill the oil cups, oil all bearings, fill the lubricators and make sure that all are in working order.
6. Throw the reverse lever over in the direction the engine is wanted to run.
7. Open the throttle slowly and bring the engine up to speed gradually, keeping the throttle lever in hand to stop instantly if necessary.
8. If the crank is not set right to start the engine, throw

ENGINE MANAGEMENT.

the reverse lever over and when the engine starts reverse it slowly.

9. Turn the throttle valve wide open and let the governor take care of the speed.

10. Close the cylinder cocks and the drain in the steam chest.

11. Adjust the cylinder lubricator to supply the proper amount of oil, generally from six to ten drops per minute.

2. *Directions for Stopping an Engine.*

1. Close the throttle valve slowly and set the reverse lever in the centre notch.

2. Open the cylinder cocks.

3. Shut off the lubricators.

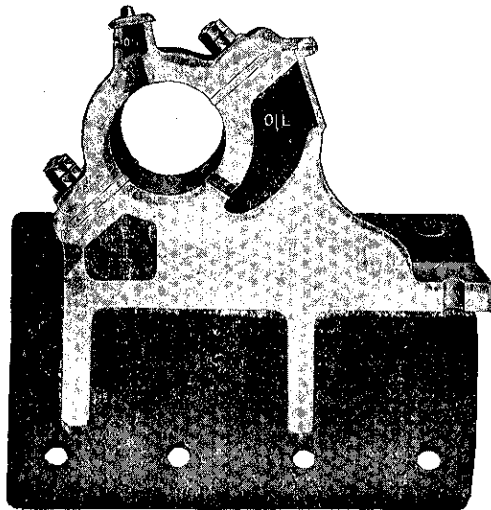
4. Wipe the engine clean while still warm and examine all bearings to see if they heat.

5. If the engine is to be stopped very long, throw the drive belt and drain all parts that need draining.

3. *Starting a New Engine.* The same general directions apply to starting a new engine as those just given, but there are other precautions that should be taken. Before turning on steam, the fly wheel should be turned over by hand to make sure that everything is adjusted properly. The engine should be run slowly for an hour or more and careful watch kept of all bearings and wearing surfaces to see that they do not heat; all bearings as well as the cylinder should be given plenty of oil on the first run as new bearing surfaces are always somewhat rough and require more oil than those that have been run for some time. If an engine runs light for an hour or two and the bearings do not heat, and

everything appears to be properly adjusted, it may be started to work.

- 4 The *Main Shaft Bearings* consist of heavy iron castings lined with either brass or babbitt, generally the latter. In the case of side crank engines the lower half of the box is frequently cast solid with the frame, but sometimes it is made separately and bolted to the frame. The bearings are



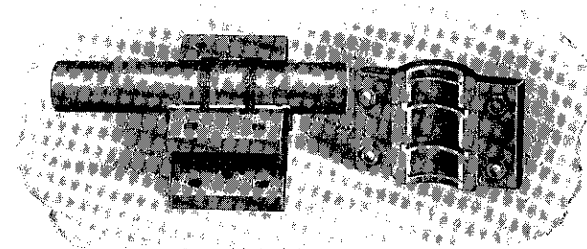
Pillow Block for Main Shaft. Fig. 221.

always made in two parts with shimming or liners between the halves, which may be taken out as the boxes wear and refitted to make the box exactly fit the shaft.

- 5 The shimming may consist of strips of cardboard, sheet

metal, or hard wood. The thickness of the shimming should be just sufficient to hold the two halves of the box at the right distance apart to accurately fit the shaft when the upper half of the box is bolted in place.

- 6 Fig. 221 shows a style of box used on a certain well-known make of traction engine. It is lined with babbitt and has an oil reservoir to insure proper lubrication. This reservoir is filled with waste and saturated with oil.
- 7 Fig. 222 shows another style of bearing or *pillow block*



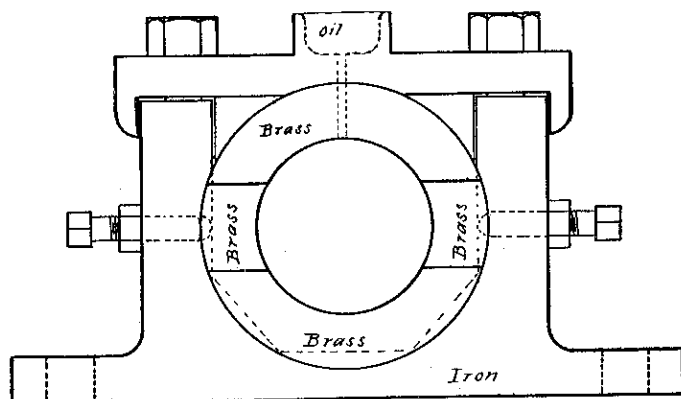
Pillow Block with Chain Oilers. Fig. 222.

as the main bearings are sometimes called, provided with chains which, resting on the shaft, revolve with it and bring up oil from a reservoir located underneath.

- 8 *Quarter Boxes.* Fig. 223 represents what is known as a *quarter box*, a style of box that is used sometimes for engine bearings. The bearing surface consists of four sections of brass arranged as shown in the drawing. The side sections are held up against the shaft by means of two set screws on each side, one at each end of the bearing. The object of

this arrangement is to set the sections in or out to compensate for whatever wear may occur, and thus keep the shaft at right angles with the centre line of the cylinder.

- 9 *Bearing Metals for Shafts* are usually made of some soft material if the shaft is of any considerable size. The substances in common use are babbitt, brass, bronze, and phosphor bronze.
- 10 In light, delicate machinery where friction must be reduced to a minimum, very hard bearings and journals are



A Quarter Box. Fig. 223.

used, as for example, the jewelled bearings in watches. Hard bearings and journals, however, would not give good satisfaction in heavy machinery. They would be more costly because they would have to be perfectly true, more easily broken, and very difficult to repair, while with ordinary

steel shafting and soft boxes all these difficulties are obviated.

- 11 A good bearing for farm machinery should be easy to repair or renew in the field at slight expense. It should also wear well and sustain the heaviest loads without heating. All bearings heat some and after running for some time will feel quite warm to the hand, but beyond that the temperature should not increase in a well made, well designed box.
- 12 An alloy for a bearing should be made up of at least two metals, one rather hard and unyielding, the other somewhat soft and springy.
- 13 The object of the softer metal is to form a springy support for the particles of hard metal. As noted above the harder the metal, the less the friction, a fact which would seem to show that a hard bearing is the best and the springy support is not needed, but hard metals will not conform to the shape of the journal, so that an unyielding metal, unless the fitting is very carefully done, will cause a concentration of the load on a few high spots, and produce rapid abrasion and heating.
- 14 There are five metals used in making bearings, namely, copper, tin, lead, zinc and antimony. All babbitts and brasses are made up with two or more of these metals, with occasionally a small quantity of some other metal.
- 15 *Bronze and Brass.* All alloys of copper and tin were formerly called bronzes, while the alloys of copper and zinc were known as brasses. At the present time there is no sharp line of difference between the two, since nearly all copper alloys contain not only tin, but lead and zinc also.

The terms bronze and brass are now frequently used synonymously.

- 16 *Babbitt.* Genuine babbitt is made of copper, tin, and antimony in the proportion shown in the following table. At the present time many different alloys are sold as babbitt, which differ very much from the genuine babbitt. Most of the anti-friction metals advertised in trade journals contain a large amount of lead and are much cheaper and somewhat inferior to genuine babbitt, but are plenty good enough for ordinary work, provided they can be bought for what they are really worth. Babbitt is so easy to adulterate and so hard to judge that a great many cheap babbitts have been put on the market and sold for a fancy price. A babbitt containing a large amount of tin is expensive, while one that is largely made up of lead should be sold for from one-third to one-half the price. The only way to buy babbitt is from a reputable dealer who has a well established reputation for fair dealing. Anti-friction metals which are widely advertised as the "best on earth," or with some equally high sounding phrase, are frequently no better than an ordinary grade of babbitt sold by the regular dealers.

TABLE I.
ALLOYS FOR BEARINGS.

	Copper.	Tin.	Lead.	Zinc.	Antimony.
Brass, Common	84.3	10.5	....	5.2	....
Brass, Hard	79.3	14.3	....	6.4	....
Brass, White	80	10	....	10	....
Bronze, Best	78	7	15	....	....
Bronze, Yellow	67.2	1.6	....	31.2	....
Bronze, Gun Metal	99	10	....	....	7.2
Babbitt, Genuine	3.7	89.1	....	....	7.2
Babbitt, Good	....	20	70	....	10
Babbitt, Cheap	....	....	87	....	13
(for light loads)					
Bronze, Phosphor	89	10	1 part of phosphorus		
Bronze, Aluminum	90—95	5—10 parts of aluminum			

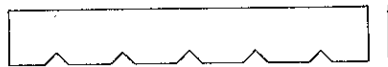
- 17 *Discussion of Bearing Metals.* The reports of tests of bearing metals show that brass or bronze is slightly better than babbitt for the reason that with the same load, the same speed of rotation, and the same amount of oil, it heats less easily. The difference, however, is quite small and for rough heavy work babbitt has been found to be more satisfactory, because, as before stated, it can be easily repaired in the field; whereas, a brass box when badly cut must be sent to a machine shop for repairs, thus causing delay and much loss of time. Moreover, the first cost of a brass box is much more than of one made of babbitt, on account of being composed of more valuable ingredients and because of the labor necessary to put it in shape.
- 18 *Phosphor Bronze.* A bearing made of phosphor bronze is considered to be somewhat superior to an ordinary brass or babbitt box. Its composition is shown in Table I, and it will be observed that it differs from a brass box only in the addition of a small amount of phosphor, whose effect is to make the bearing metal harder and somewhat more uniform in structure throughout. While it reduces the amount of friction between the bearing and shaft it has all the disadvantages which attend brass boxes and which have been mentioned heretofore; except for some special service, where it is necessary to reduce the friction to the lowest possible amount, the use of boxes of this kind is of doubtful advantage.
- 19 *Directions for Babbitting a Box.* The following directions, if carefully followed, will enable anyone to babbitt a box in an acceptable manner:

1. First cover the shaft about which the babbitt is to be poured, with paper, ordinary writing paper is about right. The edges of the paper may be stuck together with mucilage, or it may be tied on with a stout string. When a string is used, it forms an oil groove in the bearing. The paper not only prevents the babbitt from sticking to the shaft, but acts as an insulator and prevents the babbitt from cooling too rapidly when it strikes the shaft.

2. Cut two discs of cardboard to exactly slip over the ends of the shaft and place one at each end of the box for the babbitt to be moulded against.

3. Now block the shaft in the box exactly in the position desired and slip the paper discs up close to the bearing.

4. Fit the shimming between the two halves of the box, putting the same thickness on each side. Cut small V notches in the inner edge of the shimming, see Fig 224, and let



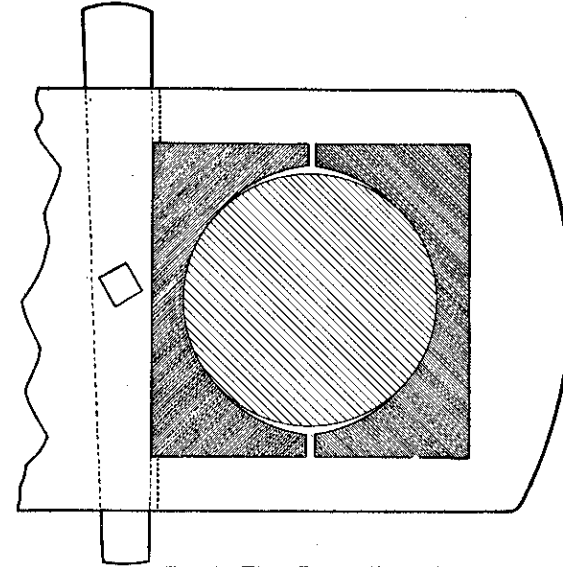
Shimming for a Split Box. Fig. 224.

it fit close to the shaft on each side. The notches allow the babbitt to flow through to the lower half of the box, but do not leave much metal holding the two halves together. After the box is poured, the two halves may be separated by means of a hammer and cold chisel.

5. After the shimming is fitted, slip the cardboards up against the box and close all openings at the end with a stiff clay paste. A small vent should be left in the clay at the

ends of the box on the upper side to allow air to escape.

6. The babbitt may be poured through the oil holes in the oil pocket at the top of the box, or these may be plugged with wood and a clay funnel moulded at one end and the babbitt poured in at this point. The plugs may then be



How to Fit a Box. Fig. 225.

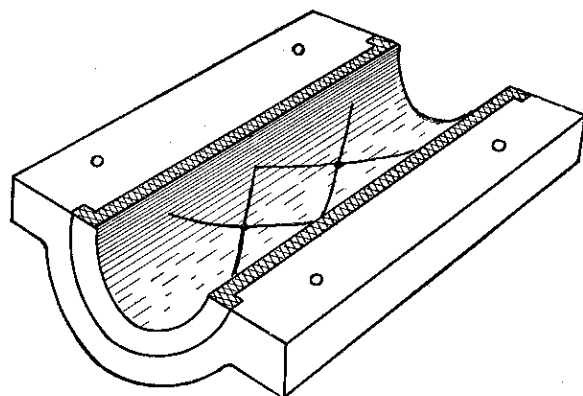
removed and it will not be necessary to bore the oil holes out.

7. After everything is in readiness, and before blocking the shaft in place, the box should be heated by burning some greasy waste in it, by means of a gasoline torch, or by means

of a large red hot piece of iron. The latter is best. If the box is not first heated it is very apt to chill the babbitt, and prevent it from running properly.

8. The babbitt should be heated until it will readily brown a pine stick.

9. In pouring be careful to prevent the slag, floating on



A Babbitt Box Showing Oil Grooves. Fig. 226.

top of the babbitt, from entering the box and pour as rapidly as possible, *never stopping* until the box is *completely* filled.

10. After the babbitt has solidified, take the cap off from the box by means of a hammer and cold chisel, and trim up the edges. Then relieve the edges of the box after the manner shown in Fig. 225. This may be done with a scraper made by grinding an old file square across the end.

Only about three-quarters of the circumference of the shaft should be in contact with the box; if it touches all around it is almost certain to heat.

11. Oil grooves should now be cut in the soft metal with a small round nose chisel, somewhat after the manner illustrated in Fig. 226.

The Cause of Hot Boxes. There are many causes that lead to the heating of boxes, a number of which are here-with enumerated and discussed on succeeding pages.

1. Boxes set up too tightly.
2. Newly fitted brasses or journals.
3. Not enough oil.
4. Gritty oil or oil of poor quality.
5. Boxes and journals badly proportioned.
6. Drive belt too tight.
7. Engine out of line.
8. Engine overloaded.
9. Boxes improperly fitted.

20 *Methods of Treating a Hot Bearing.* If a bearing begins to heat the first thing to do is to increase the feed of oil; if this does not have the desired effect, the next thing to do is to shut down the engine and make an examination to determine, if possible, what causes heating, and how to remedy it.

21 All bearings heat somewhat after they are run for a time, but one that is in proper order soon reaches its working temperature, beyond which it will not rise even if run for hours at a stretch. It takes some little experience to recognize what is actually *dangerous* heating. Of course, wherever

heating occurs it is evidence of friction and that means a loss of power, but it is not particularly dangerous to either the bearing or journal until the temperature is uncomfortable to the hand.

- 22 The most prevalent cause of hot bearings is caused by the gripping of the journal by having the boxes set up too tightly; in this case the obvious thing to do is to loosen them slightly and add plenty of oil. Sometimes a little flake graphite or flour of sulphur, introduced in small quantities with the oil, helps to make a box run cool.
- 23 In case of great emergency a bearing may be kept cool with water, but if it requires such treatment it will be pretty apt to cut.
- 24 *Method of Adjusting Bearings.* In setting up the main bearings a good method to pursue is to disconnect the connecting rod and then fit the caps to the boxes by putting in shimming between the halves. A very close adjustment can be secured by using two or three paper shims after putting in the heavier shimming. When properly adjusted the fly wheel will turn freely and no lost motion can be detected at the boxes.
- 25 The connecting rod may be connected up to the cross head and the wedge or taper key then set down very gradually until no lost motion can be detected by pushing or pulling on the rod. The adjustment of the crank pin should be made in the same careful manner, by setting the wedge in a little at a time, until a point is reached where no lost motion can be felt at the pin when the fly wheel is rocked backward and forward.

- 26 Some engineers prefer to set the boxes up just a little loose at first and then take out a little lost motion each day or half day until they finally make a perfect fit. This method is a very sure one and generally results in a very close and satisfactory adjustment. After a bearing is once properly adjusted its adjustment should not be changed unless *absolutely* necessary.
- 27 It seems impossible to take a cap off from a box and put it on again *exactly* as it was before and have the shaft run as well as it did before, even if the same shimming is used and the nuts are drawn down on the cap with the same force. Generally when a box has been loosened up it has to be brought back to adjustment again very gradually. A good engineer never touches the adjustment of a bearing until he is certain it is wrong.
- 28 *Refitting a Cut Bearing.* If a bearing heats badly, it softens and becomes cut or grooved, and the shaft cuts likewise, although it frequently happens that a box gets badly scored while the shaft remains in good shape. If a box once gets cut, it will never again run cool until refitted. Babbitt boxes are easily refitted if not too badly cut, by scraping them as smooth and true as possible with a steel scraper, which may be made by grinding off the end of a file true and square. The box should not be set up too tightly after refitting, but left a trifle loose, and gradually brought down in the course of a few days to a proper fit. It is a good plan also to put in some flake graphite or flour of sulphur to fill the little irregularities in the box and thus make a smoother and more even bearing surface. If the shaft is

cut it is hard to refit without having it re-turned; careful filing will, however, remove the burr or raised parts, and, if it is not too badly cut, it may work again all right; one or two straight grooves will not hurt very much.

29 A badly cut babbitt bearing should be repoured, and a badly cut brass bearing should be renewed. A brass bearing may be refitted by scraping, if it is not too badly cut or scored. A new brass bearing requires constant watching to prevent it from heating, because the tool used in boring it out usually leaves a large number of very small ridges or points of metal for the journal to work upon, instead of a perfectly smooth surface. Until these points of metal are bent over and smoothed down the box is very apt to heat. A new babbitt bearing, on the other hand, is not very apt to heat, if well made, because it is cast instead of being machined.

30 *Heating Through Poor Lubrication.* The object of lubrication is to interpose a thin film or cushion of oil between the journal and the bearing; if the box is set up too tightly or the load on the shaft is so heavy as to squeeze the oil out, heating is sure to be the result.

31 Almost all oil contains more or less dirt which eventually finds its way into the bearing, or else clogs up the oil holes. Sometimes this dirt consists of some gritty matter which causes considerable friction. Troubles from this source may be overcome by straining all the oil through a cloth.

32 An oil that is either too light or too heavy for the bearing, or one whose quality is otherwise poor, may cause

heating. Since oil is so easy to adulterate and so difficult to test, the consumer can hardly do better than trust to the judgment of some reputable dealer to get a good grade of oil.

33 *The Heating of Crank Pin Brasses.* Occasionally the connecting rod brasses are not properly relieved at the edges when fitted at the factory and, in consequence, run hot when they are put in service. If this is found to be the case, the brasses should be fitted as described under the heading of "directions for babbitting boxes." If the crank pin and cross head pin are not exactly parallel, the pressure will not be evenly distributed throughout the whole length of the bearing and this will cause heating, because the whole load comes upon only a small surface and, consequently, being very heavy, squeezes the oil out and causes heating. This condition may arise if the pins are not put in exactly right in either the cross head or connecting rod, or if the main shaft is not lined in properly. If the former cause makes the difficulty, the job should be turned over to a good machinist, if the latter, the engine should be realigned.

34 *Heating of Main Bearings Due to the Boiler.* When the main shaft bearings are bolted to the boiler, they will become almost as hot as the boiler, even if the engine is not run. It is only when these bearings appear to be getting hotter than the boiler that any apprehension need be felt in regard to their condition. An engineer, however, should watch these bearings carefully, nevertheless, and if he has some experience his judgment will tell him when they are getting too hot.

- 35 *Heating of Main Bearing Due to Drive Belt Being Too Tight.* As previously noted in these lessons this is one of the principal causes that lead to the heating of the bearing next to the fly wheel. When the belt is drawn up very tight the oil is squeezed out of the bearing and causes it to heat and perhaps cut. Care should be taken not to pull the drive belt up any tighter than absolutely necessary to prevent it from slipping.
- 36 *The Heating of the Eccentric* may be caused by having the strap set too tightly or by screwing up the stuffing box so hard as to cause much friction on the valve stem, thus throwing a heavy load on the eccentric. If the eccentric becomes cut through overheating, or on account of grit or dirt, it may be refitted by filing, if the work is done very carefully, or, if the case is a desperate one, it may be ground down by putting in emery between the straps and eccentric, and running the engine slowly. This treatment does not make a very smooth job, but the grooves in the eccentric will fit the ridges in the strap and make a fairly serviceable job. After it is ground down, care must be taken to wipe out every particle of the emery, then put in some flake graphite and adjust the strap. It is best not to make too close an adjustment at first, but to run for a while and gradually take up lost motion until the adjustment is complete. This may take two or three days.
- 37 *Knocks or Pounds in an Engine.* Knocks or pounds about an engine are due to lost motion or loose parts, generally, and in all cases, except noises in the cylinder, to a lack of proper adjustment of some part or parts of the engine or its connections.

- 38 A noisy engine is always a source of annoyance to an engineer, and the inexperienced man generally starts out immediately with a monkey wrench, trying all the nuts to see if he can stop it. This kind of practice is wrong. A knock does not always mean that any part is very badly out of adjustment, and in the great majority of cases it does no particular damage. When an engine begins to pound a careful engineer will first make a careful inspection to determine what is the cause, and he *never* tightens a nut until he is sure it needs to be tightened. Owing to the way sound is transmitted through the metal, very little dependence can be placed upon locating the trouble by ear. The best way to do is to depend upon sight and touch. If the lost motion is not easily located go over the engine carefully and watch each bearing and see if any lost motion can be seen or felt. In the case of the crank pin or connecting rod the lost motion can be generally felt if someone rocks the fly wheel back and forth.
- 39 *Causes of Pounding.* The following is a partial list of the causes that lead to the knocking or pounding of an engine:
1. Water in the cylinder, due to priming or to excessive condensation of steam.
 2. Loose piston rings, or the piston loose on the rod.
 3. The cylinder head loose, this can be easily seen and the remedy is obvious.
 4. The valve loose on its stem.
 5. Back pressure too high, due to the valve being improperly set.

6. The pressure plates on the back of the valve not properly adjusted.
7. Cross head shoes loose, or not properly adjusted.
8. Connecting rod brasses not properly fitted.
9. The crank pin loose in crank disc, or the crank disc loose on the shaft.
10. Lost motion between the eccentric and eccentric strap.
11. Lost motion in the reversing gear.
12. The fly wheel loose on the shaft.
13. Main bearings too loose.
14. The valve improperly set.

Items 8, 10 and 13 have already been discussed.

- 40 *Water in the Cylinder.* If the engine primes badly, water gathers ahead of the piston and causes a groaning and knocking sound in the cylinder, which the engineer will soon learn to recognize. The remedy is to open the cylinder cocks and give the cylinder a little more oil to take the place of that washed out.
- 41 *Loose Piston Rings,* that is, rings which do not fit the grooves in the piston, sometimes cause pounding, as do also broken rings. The only remedy is new rings properly fitted.
- 42 *The Valve Loose on its Stem.* If the nuts holding the valve to the stem work loose, the valve stem will move a short distance at the beginning of the stroke and then strike the valve causing a knock. This can not be ascertained without taking the steam chest cover off.
- 43 *Back Pressure too High.* If the compression is too early

at one end of the stroke, it may raise the back pressure higher than the pressure in the steam chest and lift the valve from its seat; just as quick as this is relieved by the opening of the port the valve will fall back to its seat, making a noise. The remedy is to reset the valve.

- 44 In the case of Woolf valves which are held to their seat by live steam, the valve in the live steam pipe leading to the back of the steam chest cover may be closed, allowing the valve to lift from its seat and fall back again; or, in the case of a balanced valve, the pressure plate on top may not be properly fitted.
- 45 *Loose Cross Head Shoes.* In some styles of cross heads lost motion may occur at this point, but it is readily detected by running the engine slowly and watching closely. If the engine runs smoothly in one direction and pounds when reversed, the cross head shoes need setting out. If they are set out until they pinch a piece of glazed paper they will be found to be about right. In doing this care must be exercised to set both upper and lower shoes out the same amount so that the piston rod runs exactly central in its stuffing box. This can be determined accurately enough by eye.
- 46 *A Loose Crank Pin or Crank Disc* is seldom found because they are put in place by very heavy pressure; when this is the difficulty, the only remedy generally is a new shaft; or at any rate, a trip to a machine shop.
- 47 *Lost Motion in the Reversing Gear.* Owing to the differences in the construction and design of reversing gears it is almost impossible to state in general terms just what

may be wrong, but in any event since it is all open to view, the lost motion may be either felt or seen, if a careful examination is made, and the remedy will be at once obvious.

48 *A Loose Fly Wheel* is frequently the cause of a bad knock and is due almost always to the key being poorly fitted. If the key does not fill the key way sidewise in both the shaft and the hub, lost motion is apt to occur which is not only annoying but dangerous to the fly wheel as well.

49 *The Valve Improperly Set.* If the valve is set in such a way that there is a good deal of cushion at one end and none at the other, the engine will pound at the cross head, crank pin, or main bearings, and may be at all three places. As explained in a preceding lesson, the object of the cushioning of the steam is to prevent the strain of reversing the direction of the piston, cross-head and connecting rod at the ends of the stroke from coming upon the bearings, but to make it come upon the cylinder heads instead, by meeting the resistance of the compressed steam. Therefore, if a valve is set with too much lead at one end and none at the other, the engine is liable to pound.

50 *PACKING.* In order to make either a steam or water tight joint between two metal surfaces, they must be either ground perfectly true or else a thin sheet of some soft yielding material must be placed between them. Ground joints are expensive to make and the usual practice is to use some sort of packing.

51 The material used for packing flat surfaces, such as hand holes, man holes, steam chest covers and flange unions are paper, sheet rubber, sheet lead, asbestos, wire gauze, etc. For

cylindrical surfaces such as piston rods and valve stems, there are hemp, candle wicking, asbestos, rubber, and metal packings. Each one of these different kinds of packing have some merit peculiar to themselves, and each is especially adapted for some particular service.

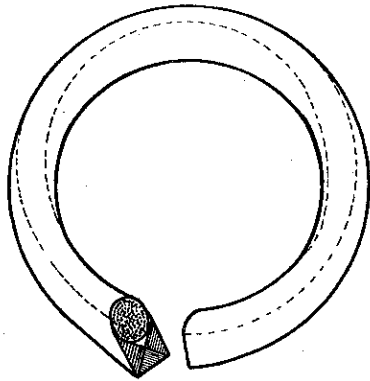
52 *Packing for the Steam Chest Cover.* A good packing for this place is tar paper, heavy manilla paper, or sheet rubber; other things have been used also with good effect, such as an old grain sack or sheet lead; the latter, however, is expensive. The surfaces packed should always be scraped clean, and if rubber is used rub graphite over both sides of it to prevent it from sticking to the metal when it softens with the heat. All the nuts on the bolts should be drawn up tightly and all given as near the same tension as possible. Then, when the steam is turned on and they begin to lengthen from expansion, go over all the nuts *again*. If this is not done the packing is apt to blow out. In cutting paper packing use a sharp knife that will not tear the edges. A torn piece of packing is useless.

53 *Packing the Piston Rod.* The best packing to use for this place is some form of patented ring packing. Most of this packing is composed of sections of rubber and hemp, encased in a woven cotton casing impregnated with graphite. An end view of a good kind of packing made in this style appears in Fig. 227. Ring packing sometimes is inserted in a continuous coil and sometimes cut in short sections and put around the rod, the sections being put in so as to break joints. Before packing the piston rod, all of the old packing should be removed with the aid of packing hooks,

which every engineer should carry with him. The usual forms in which packing hooks are made appears in Fig. 228.

- 54 Ring packing is made in one-eighth inch sizes, as one-fourth, three-eighth, one-half, etc. In ordering, measure the space between the inner edge of the stuffing box and the piston rod. If this distance is $\frac{3}{8}$ of an inch, order $\frac{3}{8}$ inch packing.

- 55 In case ring packing is not at hand, use either hemp

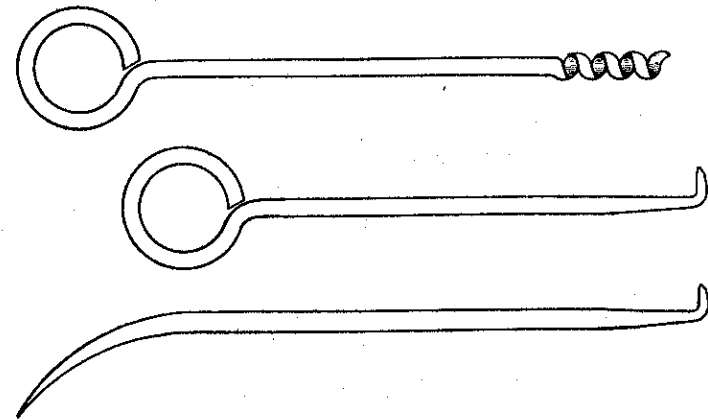


Ring Packing. Fig. 227.

or candle wicking. Hemp should always be picked apart to remove the humps, then braided, soaked in cylinder oil and coated with graphite. The box should be completely filled and the packing nut set up tightly to force it in place and then slacked back to avoid too much friction. Candle wicking should receive the same treatment as hemp with the exception that it does not need to be picked apart. The

only objection to either hemp or candle wicking is that it soon gets hard and is apt to cut the piston rod.

- 56 A piston rod when properly packed will not leak steam, but drops of water should come through and show on the rod. If the piston rod packing is screwed up too tightly it will throw a heavy load on the engine; cases have been known, in fact, where an engine appeared to have insuffi-



Packing Hooks. Fig. 228.

cient power, and the only reason was that the piston rod packing was set up too tightly.

- 57 *Asbestos Packing* is used wherever a packing is needed to withstand dry heat. It is made from a peculiar fibrous sort of rock and will not burn or melt at any temperature, but will be affected and softened by water, hence it is of no use for packing pumps or where much water can come

in contact with it. When made in the form of a heavy cord or rope, it is sometimes used to pack the piston rod or valve stems. It does not cut the rods and does not harden. Asbestos finds wider application as a packing around gas engines than it does about steam engines.

58 *Wire gauze* is sometimes used to pack large flanges, but when so used the meshes are filled with a thick paste of either white or red lead. After it is screwed up in place, the lead is allowed to harden and it is this that really makes the joint. Such a joint, however, is hard to break apart when once set.

59 **LINING UP AN ENGINE.** When a traction engine is in line, the following conditions must be fulfilled, viz:

1. The centre line of the cylinder, centre line of the guides and the centre of the main shaft must lie in the same straight line.

2. The centre line of the main shaft must be exactly at right angles with the centre line of the cylinder and in the same plane.

3. The crank pin, cross head pin, and counter shaft must all be exactly parallel with the main shaft, and this must be parallel with the drive wheel axle or axles.

The work involved in lining up an engine, therefore, consists in putting it in such shape as to fulfill the above named conditions.

60 *Preliminary Operations.* We will assume, to start with, that the engine is to be thoroughly overhauled and put in the best possible working order.

61 The first thing to do is to run the engine on to a level

floor, jack it up, take off the driving wheels and then level the main axle by measuring from a bed plate on the floor, which has first been carefully levelled. This levels the entire machine sidewise. The engine may now be levelled lengthwise by leveling on the engine frame; using in both cases a spirit level, and being careful to change it end for end while levelling.

The front cylinder head, piston, cross head, and connecting rod should now be removed, after which everything is in readiness to proceed with the operation of lining up. In this method of lining up every measurement is referred finally to the axles, which are supposed to be correct to start with.

62 *Stretching the Centre Line.* A small hard twisted cord, like a fish line, should be passed through and be made to coincide exactly with the centre of the bore of the cylinder. One end of the line should be secured to a cross piece in the head end of the cylinder, and the other fastened to a standard just beyond the main shaft.

63 In order to centre the line in the head end of the cylinder, a piece of board may be prepared as shown in Fig. 229, with a slot in one end to fit one of the stud bolts in the end of the cylinder, and with a small hole in the centre. The centre of this hole is made to correspond as closely as possible with the centre of the cylinder; then the line is passed through, drawn tight, and secured to the standard at the opposite end. The line must now be exactly centred. This may be accomplished in the easiest manner, as follows: Take half the diameter of the bore of the cylinder, and

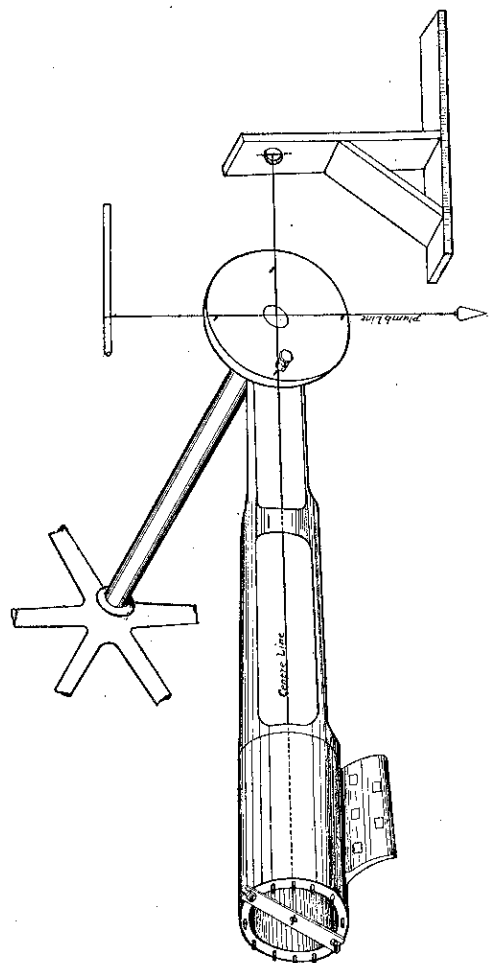
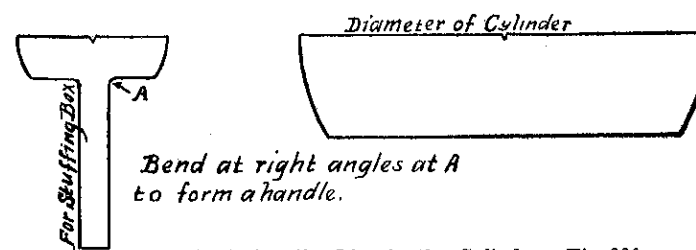


Diagram Showing How to Line Up an Engine. Fig. 229.

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strike a half circle with a pair of dividers on a piece of tin or cardboard and cut out a piece two inches wide, that will exactly fit into the counter bore at the end of the cylinder. See Fig. 230. The upper edge of this piece will extend, then, exactly across the centre of the cylinder and if it has a small V cut in the centre, it will show exactly where the line must be located. By inserting this measuring piece, first in a vertical position and then in a horizontal position,



Device for Centering the Line in the Cylinder. Fig 230.

the line may be exactly centred. A similar measuring device used in the stuffing box, will locate the line accurately in the crank end of the cylinder also. z

64 The standard should be made with a hole about two inches in diameter for the cord to pass through. Then if a stiff piece of wire or large nail be passed through a loop on the end of the cord, it may be moved a little one way or the other to make the necessary adjustment at the crank end. See Fig. 229.

65 When the line is centred it should coincide exactly with the centre line of the guides. Careful measurement will determine, therefore, if the guides are properly fitted and

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if they are not it can readily be seen what is necessary to do to make them right.

- 66 *Squaring the Shaft.* First turn the crank to the outer dead centre position and see if the centre line crosses mid way between the outer and inner shoulders of the crank pin; then turn the crank to the opposite position and note where the line crosses the pin. If the centre line comes nearer to one end when in one position, and nearer to the other end in the other position, the outer end of the shaft must be moved forward or back as the case may require. If the centre line does not cross the *middle* of the crank pin, but is at the same distance from the ends when the crank is on either centre, then the whole shaft must be moved *endwise* until it does. If the shaft is either too far out or too far in, so that the centre of the crank pin is not in line with the centre line of the cylinder, the connecting rod brasses will bear only on one edge and will consequently run badly and heat.

- 67 The next operation is to drop a plumb line straight across the centre line of the shaft. The crank should now be turned upward until it just touches this line and a careful measurement taken to determine the distance between the line and one end of the pin. When the crank is turned half way around, until the pin touches the line again, a measurement, taken at the same place, should agree with the first one; if these two measurements do not agree, then the outer bearing must be raised or lowered a sufficient amount to make them agree.

- 68 *Another Method of Squaring the Shaft* is sometimes em-

ployed in which a carpenter's square is used. This method, while not as accurate as the one just described, may be used with good effect on some styles of engines to determine roughly if the outer end of the shaft is too high or too low. In using this method, the steam chest cover is removed and a common square is held up against the steam chest walls with the blade of the square extending parallel with the main shaft. Care must be taken that the blade be squared also with the steam chest. By sighting across the top of the square and the upper edge of the shaft, the two should appear exactly parallel. If they are not, the outer end of the shaft should be raised or lowered until they are. It may not always be true, that the steam chest walls are exactly vertical when the engine is level, and if not this method fails.

- 69 *Locating the Shaft.* If the shaft must be rebabbitted, all the old babbit must be removed, and the shaft then blocked up on good, substantial blocks, which may be moved a trifle in any direction, as nearly central in the bearings as possible. The final adjustment should then be made, according to the first method described for squaring the shaft, after which the boxes may be poured.

- 70 *The Counter Shaft.* Measurements taken between the ends of the counter shaft and the ends of the main shaft should be the same at either end. Likewise, the distance between the counter shaft and the axles should agree at either end. If they do not, the countershaft needs re-adjusting; that is, if the main shaft has first been properly located.

- 71 *To Test if the Crank Pin is Parallel to the Main Shaft.* Remove the cross head pin and tighten the box fairly tight on the crank pin; then turn the fly wheel over and observe if the free end of the connecting rod moves sidewise. If it does, it proves, if the main shaft is properly located, that the crank pin is not parallel to the shaft, or else that the brasses have not been properly bored. The only safe remedy is to take the engine to a machine shop and have the crank pin re-dressed or the brasses refitted.
- 72 *To Test if the Cross Head Pin is at Right Angle to the Centre Line of the Engine.* Remove the brasses from the crank pin, and tighten those in the cross head pin. Now, push the piston to the extreme end of the cylinder and note the position of the free end of the connecting rod, relative to the centre line of the engine; then push the piston to the other end of its stroke and observe if the end of the connecting rod has moved sidewise. If it has, it proves that the cross head pin either makes an angle with the centre line of the engine or else that the brasses have not been bored and fitted properly. As in the case of the crank pin, the best remedy is to employ a competent machinist.
- 73 *What May Be Wrong if a Traction Engine Does Not Keep Up Steam, or Lacks Power.* If a traction engine does not yield as much power as it should, or if difficulty is experienced in keeping up steam, the trouble may be due to one or more of a large number of causes. Some of these have already been touched upon in this and preceding lessons; but since the subject is an important one, it is

thought best to summarize them as follows, in order to bring them all forcibly to the student's attention.

1. Soot in the flues.
2. The exhaust nozzle not pointed directly up the centre of the chimney.
3. The wrong bushing in the exhaust nozzle, or scale in the end of the nozzle.
4. Scale inside of the boiler.
5. Dirt and soot in the spark arrester.
6. A poor quality of fuel.
7. The grates and dead plate not arranged properly.
8. A leak of live steam at some point.
9. A leak of live steam from the high pressure to the low pressure cylinder of a compound engine, due to a faulty intercepting valve.
10. Main bearing screwed up too tightly, or the cross head shoes set out too far.
11. The valve badly set.

- 74 *Reversing an Engine.* An engine should not be reversed quickly when the throttle is wide open, because it throws a very heavy strain upon the cylinder head and the valve. The proper thing to do is to close the throttle and then reverse the engine, or, move the reverse lever to the centre notch and then, when the speed of the engine slackens considerably, throw the reverse lever over to the running position.

QUESTIONS, PART II.

1. Name three important directions in starting an engine, in stopping an engine.
2. What precautions should be taken in starting an engine?
3. Describe a quarter box.
4. What metals are used in making the bearings for shafts?
5. What is the difference between brass and babbitt?
6. Name five causes of hot boxes.
7. Explain how to treat a hot bearing.
8. How should bearings be adjusted?
9. Why do new brass boxes heat more readily than old ones?
10. Mention 10 causes of pounds or knocks in an engine.
11. Explain how to locate a knock.
12. Explain how an improperly set valve will cause an engine to pound.
13. What materials are used for packing flat surfaces? Cylindrical surfaces?
14. What conditions must be fulfilled when an engine is in line?
15. What is the object of stretching the centre line?
16. Explain how to square a shaft.
17. If a traction engine does not keep up steam, mention at least seven things that may need attention.
18. Explain how to babbitt a box.
19. Why is babbitt a good bearing metal for farm machinery?
20. How should a box be fitted?

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LESSON WITH QUESTIONS

PART XII.

VALVE GEARS AND REVERSING
MECHANISM.

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LESSON XII.

Valve Gears and Reversing Mechanism.

1. *Definition.* The term *Valve Gears* includes the valve, valve stem, eccentric, eccentric strap, and all other parts of the mechanism that operates or controls the valve.
2. *Classification of Reversing Gears.* All reversing devices applied to traction engines may be divided into two principal classes, namely: those which have two eccentrics, known as the link reverse, and those which have only one. The latter class may again be divided into two more classes, one in which the eccentric is made to move either across or around the shaft, and the other having a fixed eccentric.
3. *Reversing Principles.* In the case of an engine fitted with a direct acting valve, without an indirect rocker arm, the eccentric is placed 90° plus the angle of advance ahead of the crank, as shown in the accompanying diagram, Fig. 231, and the direction of rotation will be as shown by the arrow.
4. In order to reverse an engine of this kind, it is necessary to move the eccentric to the position shown in Fig. 232, making the angle A equal in both cases.
5. It is clear that if we had some arrangement of levers, whereby the eccentric could be moved from one position to the other, either by rotating it around the shaft or by providing it with a slot and sliding it across the shaft, that we

would have a practical reversing gear. A large number of traction engines are provided with gears of this class and the details of the different devices will be discussed presently.

- 6 If we had two eccentrics located as shown in Fig. 233, and could fasten the eccentric rod first to one and then to



Fig. 231.



Fig. 232.



Fig. 233.

the other, it is clear that we could also reverse the engine; or, if we could connect both of them to the valve rod in such a way that by moving a lever, first one could be made to operate the valve, and then the other, we would also have a practical reversing device.

- 7 Again, if we had an eccentric provided with a long strap, as shown in Fig. 234, and made the upper end of this strap travel in the direction C D, it is clear that if the valve stem

was connected as shown, the engine would run in the direction indicated by the arrow. A little consideration of the figure will show that if some device were arranged to compel the end of the strap to follow the path A B, the engine would run in the opposite direction. While there are a good many kinds of reversing gears used on traction engines, differing widely in details of construction, all of them are based on one or the other of the foregoing principles.

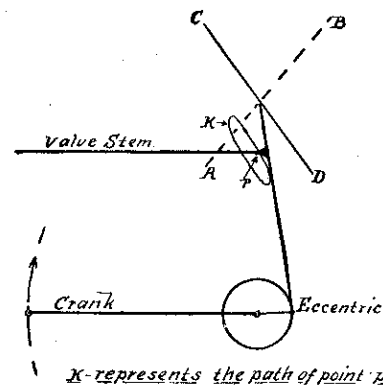


Diagram of Radial Reverse Gear. Fig. 234.

- 8 *Classification of Single Eccentric Gears.* All of the single eccentric reversing gears may be divided into three groups: radial gears, shifting eccentric gears, and the gear reverse.
- 9 In radial reverse gears the eccentric strap is provided with a long arm whose outer end is made to travel in a fixed path and thus give motion to the valve stem.

- 10 Shifting eccentric gears are arranged to move the eccentric either across or around the shaft, usually across.
- 11 The gear reverse consists of a small crank, which operates the valve rod, mounted on an independent shaft, which latter is driven by a gear which receives its motion from a similar gear mounted on the main shaft. Its principle of reversing is the same as an eccentric which is rotated around the shaft.
- 12 The *Stephenson Link*, which is shown diagrammatically in Fig. 235, is the style of link reverse used most widely on traction engines. It consists of two eccentrics E and E' connected to a curved link L , by means of eccentric rods R and R' . The link is usually suspended from its centre by means of a strap attached to a bell crank lever, pivoted at P . The reverse lever H is connected to the bell crank by means of a rod D ; consequently, when the reverse lever is set in the quadrant at q , the link is lowered until the end of the rod R comes opposite the centre of the link block B . When the reverse lever is in the other end of the quadrant the link is in its highest position and the rod R' comes opposite the block.
- 13 The valve stem is usually connected directly to the link block as shown, or sometimes by means of a rocker arm. When the link is dropped down until the end of the rod R is opposite the pin in the block, the eccentric gives motion to the valve and E' has practically no effect. With the link in this position the valve has its maximum travel, opens the ports to their fullest extent, and cuts off steam at the latest point in the stroke.

- 14 When the link is lifted to its extreme upper position, the end of rod R' is opposite to the centre of the link block and the engine is in full gear running in the opposite direc-

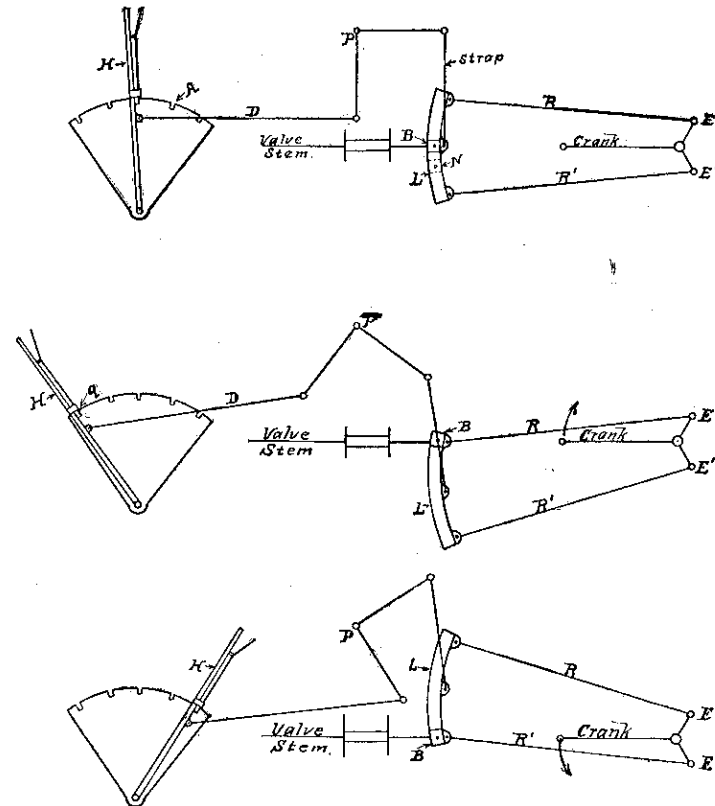


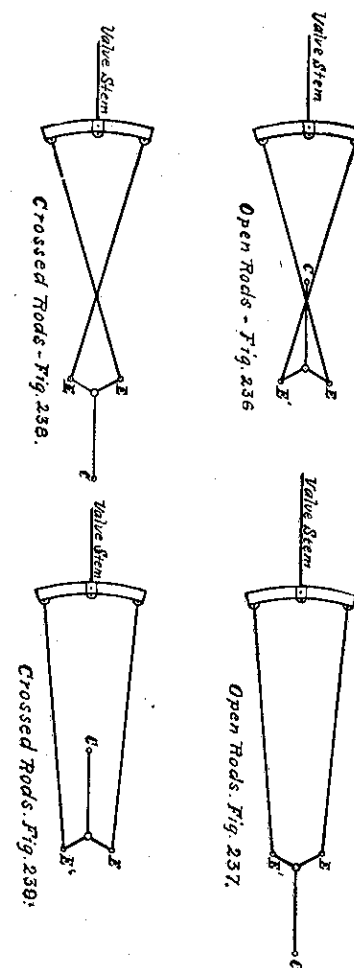
Diagram of Link Reverse Gear. Fig. 235.

tion, and eccentric E has practically no effect on the motion of the valve. If the reverse lever is placed in the centre notch of the quadrant, the link block will be in the centre of the link where it will be acted upon equally by both eccentrics and will not generally give sufficient motion to the valve to supply steam to the engine.

- 15 When the block is above the centre, the upper eccentric operates the valve; when it is below, the lower eccentric determines the valve movement.

- 16 The reverse quadrant is provided with a number of notches, usually the same number on each side of the centre, and when the reverse lever occupies one of these intermediate positions, as for example A in the upper figure, the link block will be at N. In this position both eccentrics will have some effect upon the movement of the valve, but the lower one will give the valve its direction and determine the way the engine will run. The travel of the valve will be much less than when the engine is "hooked up," and cut off will occur earlier. By providing the reverse quadrant with the proper notches, cut off may be made to occur at any point between the maximum for which the valve is designed, usually three-fourths, to almost nothing; and, consequently, the expansive property of the steam can be utilized as much as may be desired.

- 17 Moving the reverse lever nearer the centre notch is called "hooking up" an engine. Considerable saving may be effected in fuel and water by hooking up, but the saving is less in the case of a traction engine than of a locomotive, because the former is provided with a throttle governor which ex-



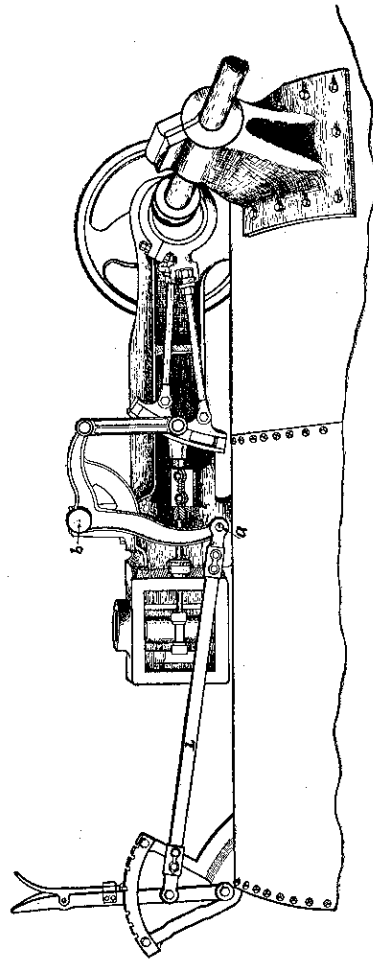
Diagrams Showing Both Open and Crossed Rods.

pands the steam in the steam chest, thus reducing the pressure, while the latter depends entirely upon the point of cut off unless the throttle is partly closed.

- 18 *Open Rods and Crossed Rods.* In considering this question, the eccentrics are supposed to point *toward the link* when the engine is on dead centre, regardless of where the crank may be. Figs. 236 and 237 show open rods, and Figs. 238 and 239 show crossed rods. In Fig. 236 the rods appear to be crossed, but a little consideration will show that when the crank is turned to the opposite centre the eccentrics will point toward the link and the rods will be open.
- 19 *Effect of Open or Crossed Rods on Lead.* "Hooking up," or moving the reverse lever toward the centre notch, *increases* the lead when open rods are used, and *decreases* the lead with *crossed* rods.
- 20 Putting the reverse lever in the middle notch will stop an engine having crossed rods, but with open rods there is always some port opening even in mid gear and the engine will not stop unless it is loaded.
- 21 The curvature of the centre of the slot of the Stephenson link has a radius equal to the length of the eccentric rods measured from the centre of the eccentric; and it is this fact which causes the change in lead for different positions of the reverse lever.
- 22 *Directions for Setting the Valve with Link Motion.* There are two accidents which are apt to happen to the valve gear in the field; namely, the valve may slip on its stem, or the eccentric may slip. The first thing to do in case trouble of this kind is suspected is to determine which has happened.

If the engine exhausts more heavily on one stroke than on the other, when loaded heavily and running very slowly, or if it lacks power, it is evident that something is the matter with the valve or eccentrics.

- 23 If the engine is placed on dead centre an inspection of the position of the eccentrics will show if they are about right. Both should make the *same* angle with the crank and appear about as shown in Fig. 235. While one can not be absolutely sure of their correct position by inspection, it is a very good check. Furthermore, most builders mark both the shaft and the hub of the eccentrics with a cold chisel and thus make it easy to reset them if they slip.
- 24 The only sure way to tell if the valve has slipped on the stem is to take the steam chest cover off and observe if it has the proper lead when the engine is on either dead centre.
- 25 *If the Eccentrics Have Slipped,* put the engine on dead centre and throw the reverse lever over into the last notch in one end of the quadrant. Now rotate the eccentric, whose rod is in line with the valve stem, until the valve shows proper lead. Reverse the engine and rotate the other eccentric in the opposite direction until it gives the valve the right lead, usually about $1/32$ of an inch, on the side next to the piston.
- 26 *If the Valve Has Slipped on the Rod* and the eccentrics are in their correct positions, proceed as follows: Put the engine on dead centre and then move the valve on its stem until it shows the proper lead on the side next to the piston. If the eccentric rods are the right length and the eccentrics are set right, the valve will be properly set.



A Link Reverse Gear Assembled. Fig. 240.

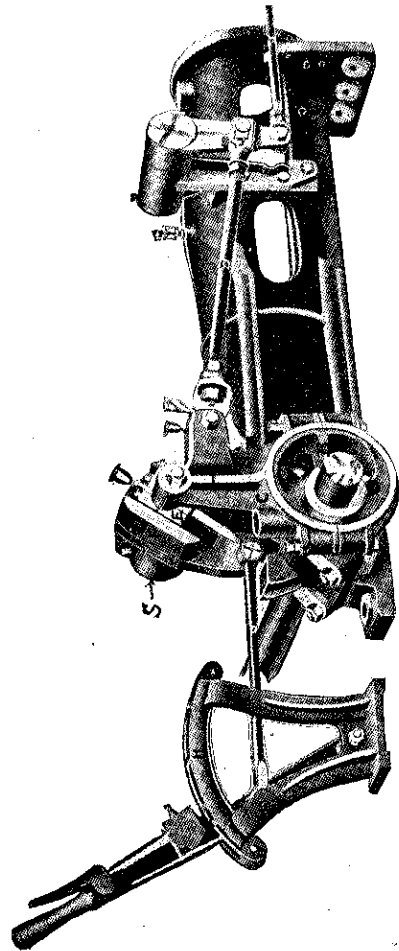
- 27 To Assemble the Link Gear and Set the Valve. 1. First adjust the length of the reversing lever I., in figure 240, so that the points *a* and *b* of the bell crank lever stand in a vertical line when the reverse lever is in the centre notch and the link block is at the middle of the link. Then, when the engine is turned over the block will move an equal distance past the mid point of the link when in full gear forward or in full gear backward.
- 28 2. Put the engine on the crank end centre and rotate both eccentrics until both stand vertically, one pointing up, the other down. Connect both to the link with rods open, making both as near the same length as possible and so that the ends of the link stand in the same vertical line when the reverse lever is in the middle notch of the quadrant. Now place the valve central over the ports and secure it to the valve stem. This locates the valve on the stem.
- 29 3. In order to find the correct length of the eccentric rods, drop the reverse lever into the last notch in the quadrant, either forward or back. Then rotate the eccentric, whose rod is in line with the valve stem, about the shaft, and note if it moves the valve as far past one port as it does past the other; if it does not do so the eccentric rod must be either shortened or lengthened until it does.
- 30 When the adjustment is made for one rod its eccentric should be left standing vertically as at first, and the reverse lever pushed over to the other end of the quadrant. The other eccentric rod may now be adjusted for correct length in a similar manner. If its length has to be changed very much the whole operation should be repeated.

- 31 4. With the engine still on dead centre, and the reverse lever in the last notch of the quadrant, roll that eccentric whose rod is in line with the valve stem in the direction the engine is to run until the valve has the right lead, usually $1/16$ th of an inch, and secure the eccentric in this new position. Now reverse the engine and set the other eccentric in the same way. Reverse again and note if the lead has been disturbed by moving the second eccentric; if it has, correct the first eccentric.
- 32 5. Put the engine on the other dead centre and see if the lead is the same as in the first position in both the forward and backward movements. It should be if all measurements have been *accurately* made and all lost motion taken up. In case the lead is not the same, correct *half* of the *error* by moving the eccentric, and the other half by moving the valve.
- 33 7. It should be kept in mind that giving the valve more lead by moving it on its stem gives it *less* lead when the engine is on the other centre. Moving the eccentric affects the lead equally on both centres.
- 34 8. In case the engine has two valves attached to the same valve stem, as in some forms of tandem compound engines, make all the adjustments for one valve, paying no attention to the other until this is done; then set the other valve for proper lead and secure it to the valve stem and the job will be completed.
- 35 *Effect of Link Motion on Steam Distribution.* When Stephenson invented the link reverse motion, his only idea, it is said, was to make a device that would change the direc-

- tion of motion of the engine. After it was completed he found that it not only did this perfectly but gave very good control of the point of cut off of steam in the cylinder, a property that made it of the greatest value on locomotives.
- 36 The link valve can be set for equal lead in either the forward or backward motions, but when so set will not have exactly equal cut off, due to the angularity of the connecting rod. If set for equal cut off it will not have equal lead. In general the valve is given equal lead for the same reason as a simple valve gear. It has also been shown that while the lead may be equal for the same cut off in both motions it will not be constant; that is, it will vary for different points of cut off, either increasing or decreasing as the engine is hooked up, depending upon whether open or crossed rods are used.
- 37 A large number of traction engines use crossed rods, although any of them may be set with the rods open. The directions given for assembling the link apply to crossed rods.

RADIAL REVERSE GEARS.

- 38 The first gear of this type to be considered is the Woolf gear. It is used more extensively than any other gear of this class and has been applied at one time or another to perhaps more than half of the different makes of traction engines.
- 39 Fig. 241 shows the essential features of the Woolf reverse. In this device the upper half of the eccentric strap consists of a long arm, the upper end of which is provided



The Woolf Reverse Gear. Fig. 241.

with a block or roller that works in a guide. This arm is provided with a connection for the eccentric rod cast solid with it and projecting at right angles from its centre line.

- 40 By means of the reverse lever the guide F may be tilted either forward or back at any angle, or be made to assume a vertical position. The action of the eccentric is to move the arm C up and down as it revolves. If now the top of the guide be tilted forward as shown in the figure, the block E, as it is pushed up by the eccentric B, must also be moved forward on one-half of the stroke and backward on the other half, thus driving the valve alternately forward and back. If the top of the guide is tilted backward, evidently the motion will be reversed, and the valve will move alternately backward and forward, thus reversing the motion of the engine.

- 41 If the guide stands vertically the mechanism is so designed that the ports cannot open more than the amount of the lead even if the shaft does turn, while if it is tilted at its greatest angle in either direction, the valve is given its maximum travel. By changing the angle of the guide it is possible to give the valve any throw between almost nothing and the maximum. The lead is constant for all points of cut off, but the cut off is not quite equal for both forward and return strokes on account of the angularity of the connecting rod, as explained for the simple eccentric.

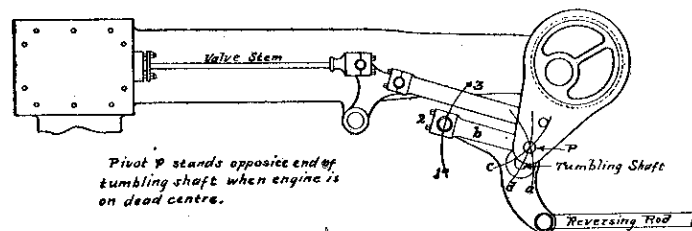
- 42 On engines where the valve stem is connected to the valve rod direct without the intervention of an indirect rocker arm, the eccentric is placed on the opposite side of the shaft from the crank pin and exactly in line with it.

- 43 The centre of the roller or sliding block must be exactly opposite and in line with the axis of the stub shaft, on which the guide rotates, when the engine is on dead centre. Since now the centre of the block is opposite the centre of the guide, tilting the guide will not move the position of the centres and no motion will be transmitted to the valve. Putting the engine on centre and moving the reverse lever back and forth to see if the valve moves is one of the tests for determining if the eccentric is properly set. This test, however, is not conclusive, because all builders do not proportion the various parts the same. As a general rule it may be stated that when the engine is on dead centre the valve will have the least movement when the reverse lever is worked, provided the eccentric is properly located, and in most engines it will have practically no movement at all.
- 44 *The Angle of the Guide* from the vertical is not the same on the full forward and full backward motions and should not be, because when so adjusted the valve will not have equal travel, but will travel considerably past the ports on one motion. In case it becomes necessary at any time to make this adjustment, take off the steam chest cover and adjust the length of the reversing rod until, when the engine is turned over, the valve travel is nearly equalized.
- 45 *Directions for Setting the Woolf Reverse.* First, take up all lost motion in all parts of the valve gear; this is very important because a very little lost motion will affect the correct working of the valve very materially.
- 46 Second, put the engine on dead centre and set the eccentric in line with the valve stem, either on the same side as

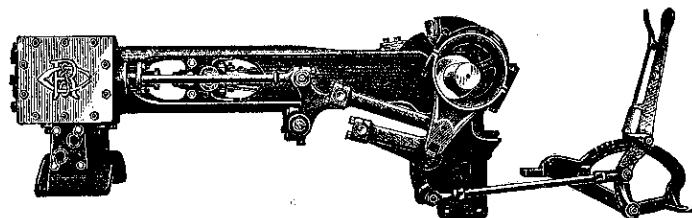
- the crank or else on the opposite side, depending upon whether an indirect rocker arm is used or not. If no rocker arm or a direct rocker arm is used the eccentric should be on the opposite side from the crank. Now throw the reverse lever backward and forward and find a place for the eccentric where the valve moves least and secure the eccentric to the shaft by means of set screws.
- 47 Third, give the valve the proper amount of lead on the side next to the piston and then put the engine on the other centre and see if the lead is the same; if it is not, move the valve on the stem a distance equal to one-half of the difference between the two leads. All that can be done with this valve gear is to equalize the lead; it can not be changed from what it was designed to be.
- 48 *Setting the Valve by Listening to the Exhaust.* This may be accomplished with any type of valve gear if the eccentric is properly located. The method of procedure is to put the engine on a heavy load and run slowly; then lengthen or shorten the valve stem until a point is found where the exhaust sounds the same at both ends of the stroke.
- 49 *Another Type of Radial Reverse Gear* is shown in perspective in Fig. 242, and diagrammatically in Fig. 243. The long arm of the eccentric strap resembles the Woolf, except that instead of having a block and slide to guide the lower end, it is provided with a radius link b which forms the arc in which the end of the strap must travel. The free end of the link b may be made to assume different positions between 1 and 3 depending upon the position of the

reverse lever. It will be observed that the two extreme arcs *a* and *c* correspond in general direction with the extreme positions of the guide in the Woolf gear, and the arc *d*, when in mid gear, corresponds with the vertical position of the Woolf guide.

50 This gear gives substantially equal lead and equal cut



Another Style of Radial Reverse Gear. Fig. 242.



Perspective of Preceding Figure. Fig. 243.

off for both forward and return strokes. Like all gears of this class it provides for a quick opening of the port at admission, and a quick sharp cut off.

51 As generally built the engine will take steam seven-

eighths stroke in full gear and one-eighth stroke when hooked up in the last notch, thus providing for as many grades of expansion of steam as necessary.

52 *Directions for Setting the Valve and Eccentric.* The starting point is to place the reverse lever as far back as it will go against the stop on the quadrant, then put the engine on the crank-end centre by turning the band-wheel forward.

53 The next step is to set the eccentric almost 180 degrees ahead of the crank pin and fasten the same with one of the set screws just lightly for a trial, then place the valve on the stem and set it to the steam port nearest the crank pin, leaving $1/16$ of an inch opening.

54 After this has been carefully done turn the band wheel forward and put the engine on the head end centre and see if the steam port shows $1/16$ inch opening. If it does, the valve is properly set.

55 Should this last port show a $1/8$ inch opening, divide the difference, half by moving the valve on the stem, the other half by moving the eccentric; then the opening or lead on the crank end will not be affected. These same adjustments are necessary should the port be closed instead of having the $1/8$ inch opening.

56 It is impossible for an eccentric on engines provided with this gear to slip as it is keyed to the crank shaft. The way in which it is fastened, is as follows: A $5/8$ inch hole is drilled in the crank shaft about one-half inch deep in which an iron plug is driven very tightly. This plug is allowed

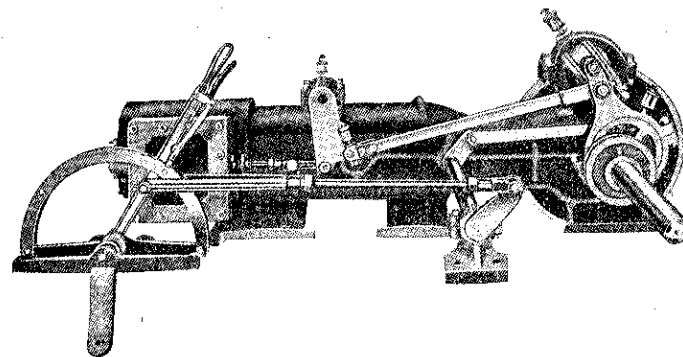
to protrude above the shaft $\frac{1}{4}$ inch. It is then filed flat on each side and the eccentric, which is slotted, is slipped over this and the two set screws tightened down solid.

57 After a number of years of service of an engine, it sometimes becomes necessary to shift the eccentric in order to get the proper valve travel. This can be done by putting in another plug and filing it flat on only one side of the centre, which will allow the eccentric to be shifted slightly from its original position. This arrangement does away with cutting another keyway in either crank shaft or eccentric.

58 *Wearing Down of the Main Bearings.* In this type of radial reverse gear, the distance between the centre of the mainshaft and the tumbling shaft or guide pivot must be a constant distance. A variation of a thirty-second of an inch at this point from what the gear is designed for, will cause the valve to distribute the steam badly to the cylinder. Consequently, after an engine has run for a few years the main shaft bearing will be too low, due to wear, and must be re-babbitted in order to put the valve in exact adjustment again.

59 *The Springer Reverse Gear* is almost identical with the Woolf, the principal difference being that the guide, instead of being straight, is made in the arc of a circle. This gives practically the same motion to the end of the eccentric strap as the reverse gear just described. It is claimed this reverse gear provides equal lead and equal cut off. See Fig. 244. The directions for setting the Woolf gear apply both to this gear and the Grimes reverse.

60 Another Interesting Reverse Gear with properties similar to those just described, appears in Fig. 245. In this gear the eccentric is placed a little more than 90° ahead of the crank and motion is transmitted to the valve by means of a rocker arm m attached to the free end of the long arm of the eccentric strap s . By shifting the pivot about which the radius rod l swings to a , b or c , the outer end of the strap

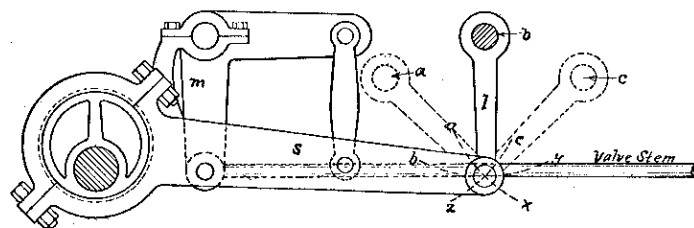


The Springer Reverse Gear. Fig. 244.

is compelled to follow the paths ax , by or cz respectively. These arcs, it will be observed, follow the general direction taken by the ends of the strap in all of the radial gears previously described, provided the drawing is held with the valve stem pointing upward.

61 In all other gears of this class, the lead can readily be equalized but can not be made other than what it is designed for, but in this gear provision is made for changing the lead within certain limits.

- 62 *Discussion of Radial Gears.* As noted in the description of each of the different styles, these gears give equal lead and practically causes equal cut off on both the forward and return strokes, thus enabling the engine to do as much work on one stroke as on the other, a feature which tends toward a more nearly uniform speed. On the other hand, these gears are very sensitive to lost motion in any part, and must be kept in nice adjustment to do their best work. They provide a quick opening of the valve at the beginning



A Well Known Radial Gear. Fig. 245.

of the stroke when steam is most needed, and provide, also, a fairly quick cut off, which tends toward economy in the use of steam.

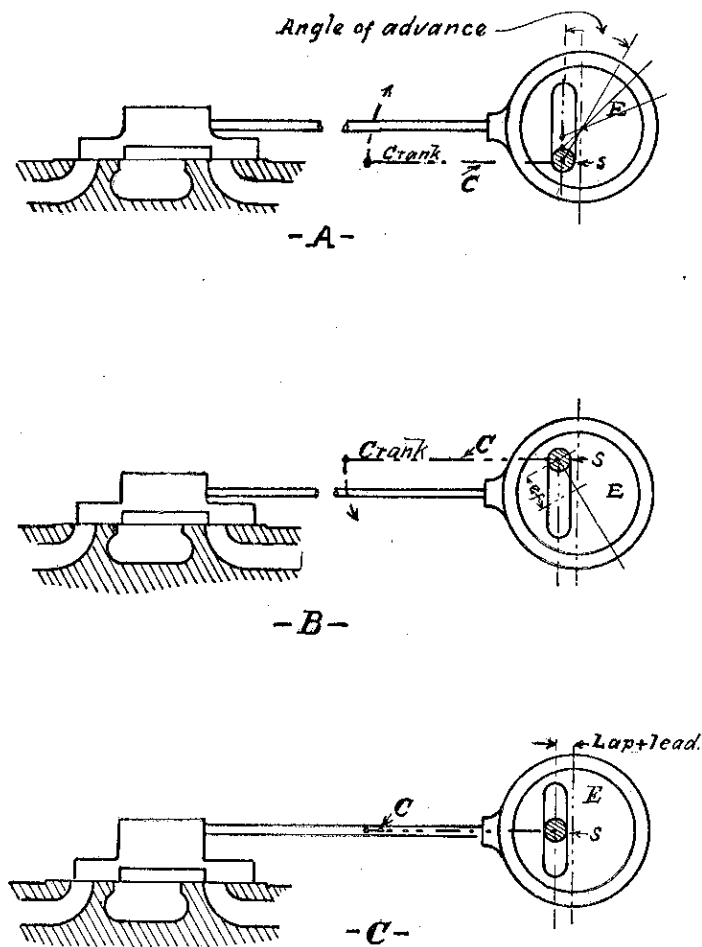
SHIFTING ECCENTRIC REVERSE GEARS.

63. In this type of reverse gear, the shaft passes through a slotted eccentric, which, instead of being keyed to the shaft, is free to slide across the face of a disc. The disc is keyed securely to the shaft, so that changing the position of the eccentric on the disc changes its relative position on the shaft.

- 64 Fig. 246 illustrates the general principle. S is the shaft, C the crank, and E the eccentric. The slot in the eccentric does not pass through its centre but is shifted to one side of the centre the amount of the outside lap plus the lead. The three diagrams, A, B and C, represent the position of the eccentric when in full gear forward, full gear backward, and mid gear respectively. By referring to the diagram A, it will be observed that the angle of advance of the eccentric increases as it nears the centre of the slot; but since the centre of the eccentric describes a straight line across the shaft, the lead remains practically constant for all positions of the reverse lever.

- 65 *Hooking Up the Slotted Eccentric Gear.* When the reverse gear is in full gear as shown in A or B, Fig. 246, the throw of the valve is equal to *ef*. As the reverse lever approaches mid gear the throw of the valve becomes less and less until at that position the movement of the valve is equal only to the lap plus the lead. Since the throw of the valve and the angle of advance changes, it is clear that the valve can be given any point of cut off between almost nothing and the maximum for which it is designed by providing the reverse quadrant with the proper notches for locking the reverse lever.

- 66 The steam distribution is somewhat affected by the angularity of the connecting rod and cut off does not occur at the same point on the forward stroke that it does on the return stroke. Since the valve has some opening when the reverse lever is in the centre notch, the engine will not stop when in mid gear unless loaded.



Diagrams of a Slotted Eccentric Reverse Gear. Fig. 246.

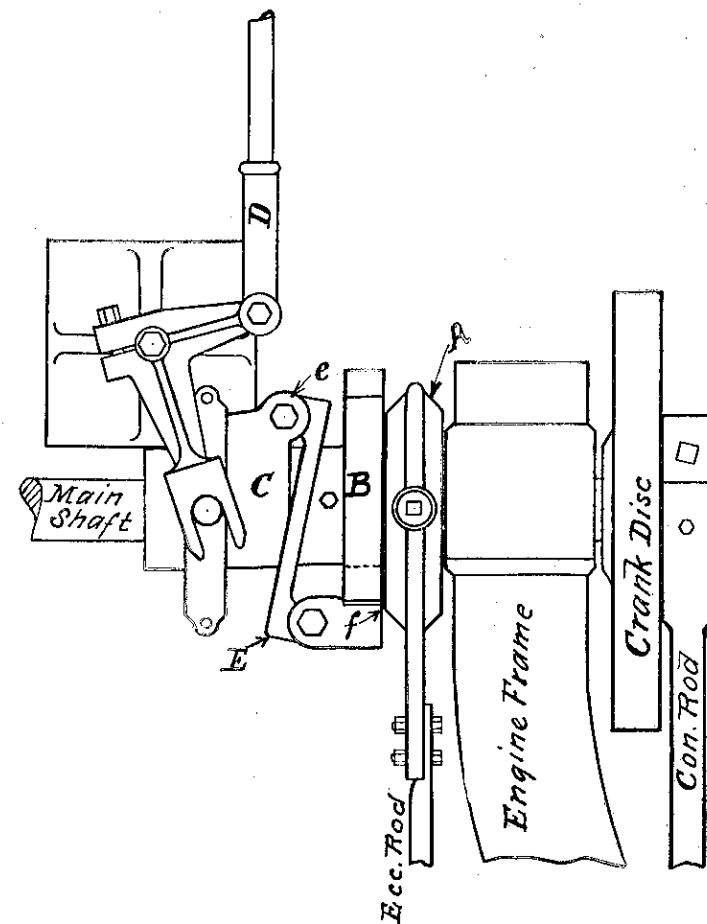
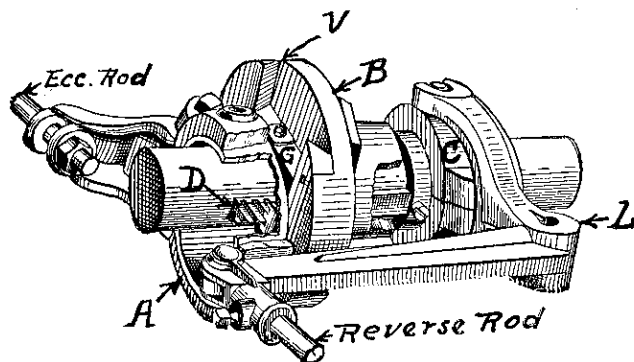


Diagram Showing Mechanism of a Certain Style of Slotted Eccentric Reverse Gear. Fig. 247.

- 67 *Practical Examples of Slotted Eccentric Gears.* Fig. 247 shows a gear of this kind arranged to slide across the shaft by means of toggle levers. Referring to the drawing, A is the eccentric which slides on guides attached to the hub B, which latter is secured to the shaft by means of a set screw. C is a sleeve which slides back and forth on the shaft, actuated by the bell crank lever which in turn



Another Method of Shifting the Eccentric. Fig. 248.

receives its motion from the reverse lever through rod D. A forked rod E is attached to this sleeve at *e* and to the eccentric at *f*. When the eccentric is moved away from the eccentric rod, E becomes more nearly parallel with the main shaft and pulls the eccentric across the shaft. When the sleeve is moved in the opposite direction the eccentric is pushed the other way across the shaft. The forks of the bell crank lever engage with gudgeons cast in a strap which

- loosely encircles the sleeve C. This allows the sleeve, rod D, and the eccentric A to revolve with the shaft.
- 68 *Another Style of Slotted Eccentric Gear* is made the subject of illustration in Fig. 248. A is the eccentric which carries a guide block G, which slides in the guides V of the disc B. This disc is fastened to the shaft by means of set screws and revolves with it at the same time carrying the eccentric and sliding sleeve C. A rack D having teeth cut on its outer surface at an angle of 45° is secured to this sleeve and meshes with a similar rack, secured to the inner side of the guide block G. When the sleeve C is moved backward or forward on the shaft by means of the bell crank lever L, this rack causes the eccentric to move up or down across the shaft and so either reverses the engine or hooks it up. If the reverse quadrant is provided with the proper notches the valve can be made to cut off steam at any desired point. Stop screws are provided in both ends of the eccentric guide to limit the movements of the eccentric.

- 69 *Directions for Setting the Slotted Eccentric Gear.*

1. Put the engine on dead centre and see that all lost motion is taken up in the reverse gear.
2. Move the disc which carries the eccentric guides about the shaft until a position is found where moving the reverse lever from one end of the quadrant to the other will bring the valve back exactly to its original position. Several trials may be necessary before the right location of the eccentric is found.
3. Now move the valve on its stem until it has the correct

lead, usually from $1/32$ to $1/16$ of an inch at the port nearest to the piston.

4. Turn the engine over to the other centre and see if the lead is the same. If there is any difference, move the valve a distance equal to half of the error.

70 Engines which have no provision for changing the length of the eccentric rods readily, or of moving the valve on its stem are provided with flat rods riveted together. If the lead can not be equalized in any other way these rivets may be removed and the holes filed out on one side or the other enough to make the adjustment. This is rarely ever necessary, however. The hub of the eccentric disc is usually marked at the factory, and if it has slipped it can be put back by shifting to the original mark.

71 The *Swinging Eccentric* reversing gear is represented diagrammatically in Fig. 249. The full lines in diagram B show the eccentric in position for full gear forward. E is the eccentric which is provided with an arm pivoted at P. S is the main shaft and c is the centre of the eccentric. In this position ac is the throw of the eccentric and b shows the distance the valve has moved from mid position at the beginning of the stroke, or, in other words, the lap plus the lead. The slot in the eccentric allows it to be shifted downward across the shaft to the position F, shown by the dotted lines. When the eccentric is at E the crank will turn in the direction of the arrow, when at F it will turn in the opposite direction and the engine will be reversed.

72 Diagram A shows the position of the eccentric when the reverse lever is in the centre notch. The line mn passes

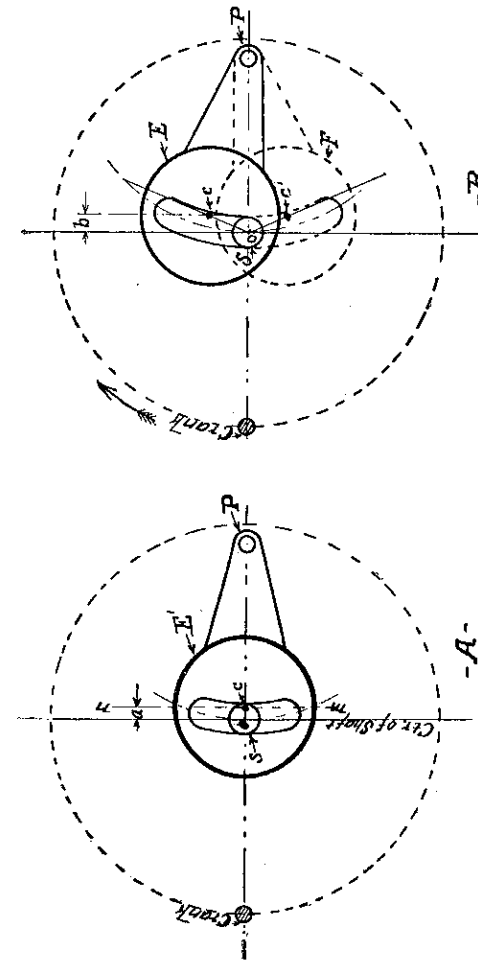


Diagram of the Swinging Eccentric Reverse Gear. Fig. 249.

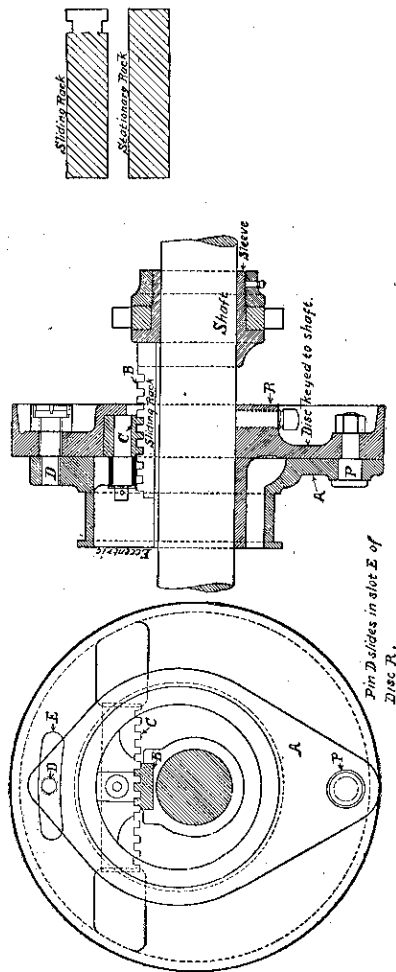
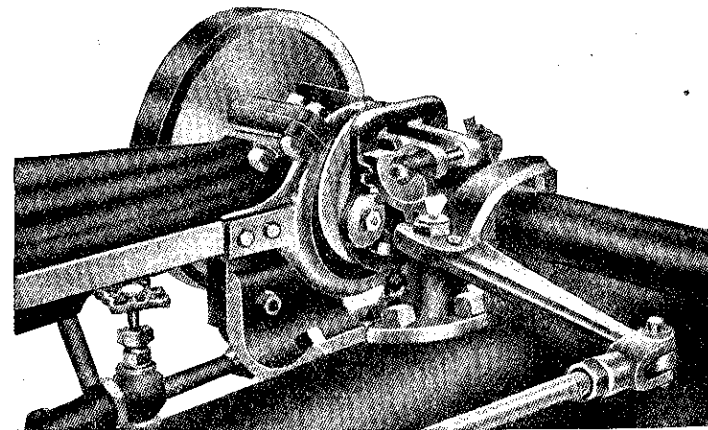


Diagram Showing Mechanism Used for the Swinging Eccentric Gear. Fig. 250.

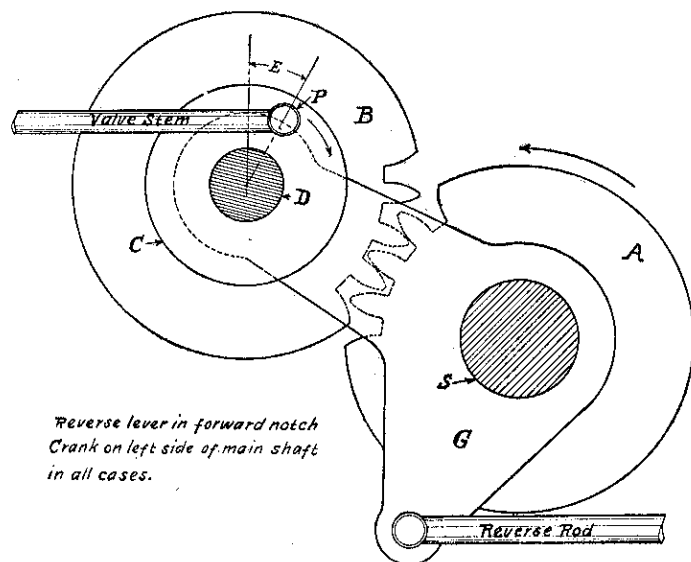
through the centre of the eccentric and *a* shows the amount the eccentric is offset from the centre of the shaft, and if the valve gear is so designed as to close the ports when the reverse lever is in the centre notch, and the engine is on centre, it represents the outside lap of the valve. Since the centre line of the slot curves away from the line passing through the centre of the main shaft it is clear that as the engine approaches full gear the lead must increase. Re-



The Eccentric is Provided with a Curved Slot and is Moved by Means of a Segment Gear and Rack. Fig. 251.

ferring to the diagram it will be noticed that *B* is greater than *A*, a fact which shows that the lead increases as the reverse lever is dropped down near the end of the quadrant. In the first type of shifting eccentric the centre of the ec-

centric moved in a straight line across the shaft, thus keeping the lead practically constant, but in this style, the eccentric C moves in the arc of a circle whose centre is at P and the lead varies a slight amount, depending upon the length of the radius Pc. It must be understood that Fig.



Gear Reverse. Engine Running in the Belt. Fig. 252.

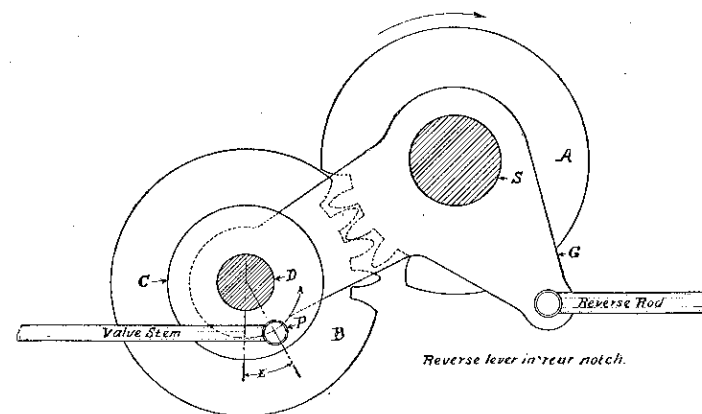
249 is only a diagram and does not show how the mechanism is actually constructed.

- 73 An Example of a Reverse Gear of This Kind appears in Fig. 250. In this case the eccentric is cast with an arm A,

pivoted at P, which is given motion with two 45° racks B and C, just as described for Fig. 248. The centre of the eccentric moves through an arc, whose radius is the distance from P to the centre of the eccentric.

- 74 Fig. 251 shows still another device for the shifting of the eccentric, by means of a rack and segment pinion. In this case the slot in the eccentric is also curved.

- 75 The Gear Reverse. Figures 252, 253 and 254 represent



Gear Reverse Engine Running on the Road. Fig. 253.

the three positions of this gear when the reverse lever is in the forward notch, backward notch, and middle notch respectively.

- 76 S is the main shaft, A is a spur gear secured thereto, and B is another spur gear of the same size keyed to a short auxiliary shaft D. On the end of shaft D there is fastened

a crank disc C, having a crank pin at P. A gear box G, provided with an arm below to which the reversing rod is attached, encloses shafts D and S and holds the former at a fixed distance from S.

- 77 The valve stem is attached to the crank pin P, which is caused to rotate by means of gears A and B and thus drives the valve. This small crank disc acts exactly the same as

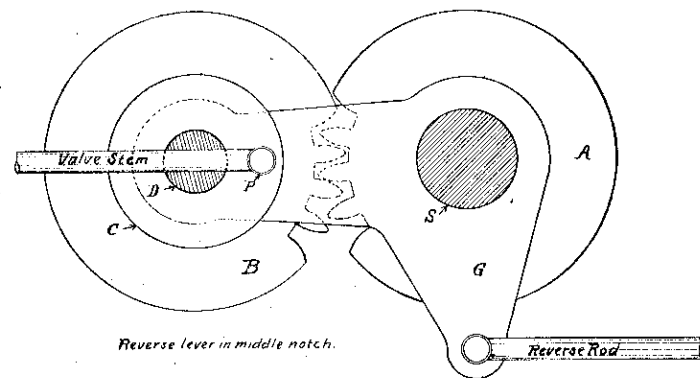


Fig. 254. Gear Reverse, Reverse Lever in Middle Notch.

an eccentric, but since it revolves in a direction opposite to that of the main shaft, it must be placed 90° plus the angle of advance *behind* the crank. The angle of advance is shown at E and E' respectively, and the direction of rotation of the crank and of the pin P, is shown by the arrows.

- 78 In changing from full gear forward to full gear backward, as represented by diagrams 252 and 253, the small disc D must be rotated through an angle of approximately

240° . In order to do this the gear box G must be made to rotate through an angle of one half this amount, or 120° , when the reverse lever is shifted to the other end of the quadrant. The reason for this difference in the angle becomes plainly evident when one considers a point on one gear which rotates about another of equal size. For example, if gear B were made to rotate entirely around gear A, it would turn once on its own axis and once in space around A, making, therefore, two complete revolutions.

- 79 *Discussion of the Gear Reverse.* The principle upon which this reverse gear works is that of revolving the eccentric around the shaft. In fact, the positions of the pin P in diagrams A and B are exactly the positions an eccentric would assume with an indirect valve fitted with an indirect rocker arm, and the method of moving this eccentric from one position to another is by rotating it about the shaft.

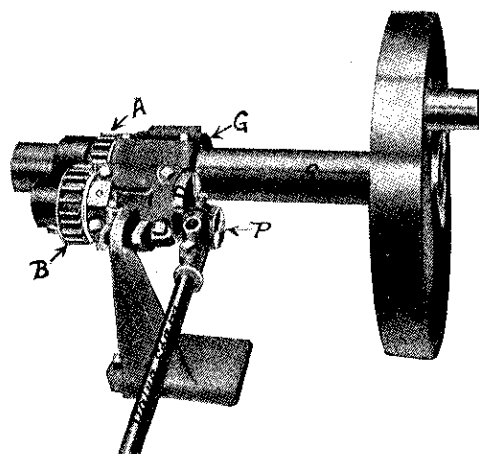
- 80 When the reverse lever is in the middle notch, the pin P is as shown in figure 254, and the valve is pushed to its extreme position to the right, thus admitting steam in front of the piston and preventing it from getting in behind. Consequently setting the reverse lever in the centre notch will stop the engine.

- 81 A careful inspection of the diagrams will show that this gear can not be hooked up, but must always cut off steam at whatever point in the stroke it is set for. Consequently under light loads the governor throttles the steam and the greater part of the expansion occurs in the steam chest.

- 82 *Directions for Setting the Gear Reverse Valve.*

1. Put the engine on dead centre with the crank pin nearest the cylinder.

2. Set the screws that are in the top and in the bottom of the stop plate or casting in front of the crank shaft, about three-quarters of an inch from the lugs of the stop plate, simply as a preliminary operation, as this is probably not their final position.
3. Move the reverse lever until the gear box strikes the screw in the top of the stop plate.
4. Make a prick punch mark on some convenient part of



Perspective of Gear Reverse. Fig. 255.

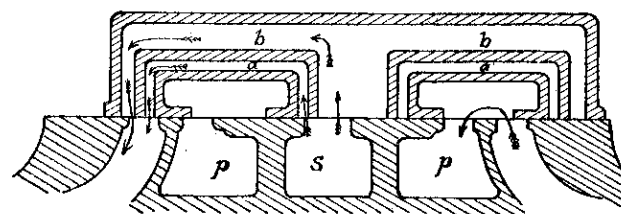
the steam chest or stuffing box, set one leg of a pair of compasses in this mark and with the other point of the compasses scratch a mark on the valve stem.

5. Throw the reverse lever over to the other end of the

VALVE GEARS AND REVERSING MECHANISM

quadrant and see if the valve stem comes back to the original position.

6. If it does not do so the gear on the main shaft must be moved until a point is found where the valve stem will return to its original position when the reverse lever is moved to the opposite end of the quadrant. It may be necessary to make several trials before the correct position is found.



The Giddings Valve. Fig. 256.

When correctly located, the gear must be fastened securely to the main shaft with the set screws.

7. Now set the valve on its stem with the port at the head end of the cylinder open about $1/32$ of an inch.
8. Put the engine on the opposite centre and see if the valve has the same lead.
9. If the lead is not the same adjust the screws in the stop plate until the valve again shows $1/32$ of an inch lead.
10. Now reverse the engine and again adjust the stop screws in the other end of the stop plate till the right lead is obtained. The valve should now be correctly set.
11. Before turning on steam see that all parts are prop-

erly adjusted and the stop screws locked in place. Fig. 255 shows this gear as applied to an engine.

- 83 *Rotating the Eccentric About the Shaft.* There is no reversing gear applied to traction engines at the present time in which the eccentric is rotated on its own axis about the main shaft. However, there was such a gear used a number of years ago in which the eccentric was secured to the shaft by means of a pin. When the engine was reversed this pin was released, the eccentric remained stationary, and the shaft revolved to the reversed position for the eccentric, when the pin dropped back into place, locking the eccentric to the shaft. With such an arrangement the engine could only be reversed when in motion and moving slowly. It could not be hooked up and the shock to the eccentric was rather severe.

- 84 *The Giddings Valve.* A sectional view of this valve appears in Fig. 256. Steam is admitted to the inside of the valve through the passage S, from whence it passes in the direction of the arrows to the steam ports. The exhaust passes out through either of the passages P. The valve is double ported as shown at *a* and *b* and provides a wide port opening with a small movement. Since steam enters from the under side it would lift the valve off its seat, if no pressure came upon the top side. The balancing of the valve is accomplished by a small needle port, not shown in the drawing, which admits steam to the steam chest; another needle port allows the steam to escape from the steam chest to one of the exhaust D's of the valve, thus preventing an

accumulation of pressure on top of the valve which would make it run heavy.

- 85 These valves are always used in connection with shifting eccentric gears. Since the ports are on the inside of the valve, the lead can not be seen. The builders get around this difficulty by marking both the edge of the valve and the steam chest, so in setting the valve all that is necessary to do is to make these marks coincide when the engine is on either centre. Otherwise the operation of setting the eccentric is the same as for the other shifting eccentrics just described.

QUESTIONS FOR PART XII.

1. What does the term "valve gear" include?
2. In what three ways may an engine be reversed?
3. How are single eccentric reverse gears classified?
4. Show, by means of diagram, the position of the two eccentrics and the crank of a link reverse engine.
5. What is meant by hooking up an engine?
6. What is meant by "open rods," (b) crossed rods?
7. What is the effect of open or crossed rods on the lead?
8. Explain how to reset the eccentrics of a link reverse engine in case they have slipped.
9. What is the effect of hooking up a link reverse gear?
10. How would you set the eccentric of a radial reverse gear?
11. Mention two types of radial reverse gears and show how they differ from each other.
12. What is the effect of the radial reverse gears on steam distribution?
13. How may shifting eccentric gears be classified?
14. Can slotted eccentric gears be hooked up?
15. Give directions for setting the slotted eccentric gears.
16. Describe the gear reverse.
17. Can the gear reverse be hooked up?
18. What is the effect of the swinging eccentric gear on the lead?
19. What effect have those gears with a straight slot in the eccentric, on the lead?
20. How does the Giddings valve differ from other valves?

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LESSON WITH QUESTIONS

PART XIII
FRICTION, LUBRICANTS AND LUBRICATORS.

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

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LESSON XIII.

FRICTION, LUBRICANTS AND LUBRICATORS.

1. *Friction* tends to destroy motion in every direction. It may be defined as the resistance which a body meets with from the surface upon which it moves.
2. If a body is set in motion, friction will bring it to rest unless the motive force is continued and is sufficient to overcome the friction. It is impossible to construct a frictionless machine, because no surface can be made absolutely smooth and true. The best that can be done is to reduce friction to the lowest possible amount, by correct design, by careful workmanship, and by proper lubrication.
3. *The Laws of Friction.* There are five laws or principles relating to the friction of plain surfaces that are commonly accepted and which are true, at least within certain limits. These laws may be expressed as follows:
4. *Law 1.* Friction varies directly in proportion to the pressure on the surface; for example, doubling the pressure doubles the friction, and trebling the pressure trebles the friction, the area of the surfaces in contact, of course, remaining constant.
5. *Law 2.* Increasing or decreasing the areas of the surfaces in contact does not change the friction, provided the *total* pressure, the speed, and the character of the surfaces remain unchanged. The same amount of friction distributed over a large area, however, reduces the tendency of the bodies to heat or wear.

- 6 *Law 3.* In general, friction is greater between rough surfaces and less between surfaces that are smooth.
- 7 *Law 4.* Friction does not change with a change of speed in the moving bodies so long as they are in continuous motion. Friction, however, is greater at the beginning of motion and more force is required to start a body than to keep it in motion once it is started.
- 8 *Law 5.* Friction is greater between the same substances, generally, than it is between different substances. For example, the friction between a steel journal and a steel box is greater than between a steel journal and a brass box.
- 9 *Beneficial Effects of Friction.* While friction, it is true, consumes energy and lowers the efficiency of all machines, it is not entirely an evil. Friction enables the wheels of locomotives to cling to the rails and thus pull a load. Without friction the brakes would not be effective in stopping a car, and if it were not for friction it would be impossible to walk or run. Everyone knows how hard it is to walk on a very hard smooth floor or on an icy pavement where there is little friction between our shoes and the surface we are walking over.
- 10 The general effect of friction is to cause heat in the bearings of machinery. As will be shown in a subsequent lesson, there is an exact relation between heat and work, consequently if it requires a great deal of work to turn a shaft in a bearing, heat will be produced and the amount of heating will be in direct proportion to the work done in order to overcome the friction.
- 11 Friction is sometimes classified as rolling friction, as be-

- tween a revolving shaft and its bearing, and sliding friction, such as exists between the cross head and guides. These two kinds of friction apply to solids. Then there is fluid friction, which exists between the molecules of a fluid in motion.
- 12 *The Coefficient of Friction.* If a body presses upon another with a force of ten pounds and it requires one pound of force to move it on a horizontal plane, the coefficient of friction will be $1/10$ of the load, or 10%. The coefficient of friction varies between different substances, and depends also upon the character of the surfaces in contact, being greater between rough surfaces than between smooth ones.
 - 13 As illustrating the laws of friction, suppose we have a rectangular iron block six inches wide, eight inches long and three inches thick, finished the same on all sides and weighing 36 pounds. Suppose it be laid down on its largest side on a smooth table, and it is found that a force of 5.4 pounds is necessary to move it, as shown by a spring balance. The coefficient of friction will be in this case, $36 \div 5.4 = 15\%$. If the block be turned on end so that it has twelve square inches in contact with the table, it will still require a force of 5.4 pounds to move it, showing that the amount of friction is independent of the area of the surface when the pressure is the same. The load upon each square inch in the second case is, of course, much greater than in the first case.
 - 14 *Losses Due to Friction.* The friction losses in engines vary a great deal. A few years ago in stationary engines

it required from 15 to 20 per cent of the total power of the engine to run it without any load. At the present time some of the high speed engines consume only from 3 to 5 per cent of their power in friction.

- 15 Traction engines running in the belt require perhaps 10% of their total power to overcome friction. When running on the road the loss is undoubtedly very much higher, but no authentic tests are available to determine the average amount.
- 16 The losses due to friction in traction engines depend very largely upon how the engine is "lined up," how it is lubricated and how well the different parts are proportioned and fitted. In any event the friction losses in traction engines exceed those in stationary engines equally well made, due to the larger number of moving parts of the former, and the long bearings and wide gearing necessary for heavy work.
- 17 Prof. Thurston says, "that as a result of a large number of experiments, the greatest friction loss in stationary engines occurs in the main bearings, and in every instance it amounts to from one-fourth to one-third of the total frictional resistance of the engine."
- 18 *Distribution of Friction Losses.* A summary of the results of tests on stationary engines by Prof. Thurston shows that approximately 40 per cent of the entire friction of stationary engines occurs in the main bearings, 25 per cent in connection with the piston and piston rod, 10 per cent at the cross head, and from 10 to 30 per cent in the valve, valve stem and eccentric strap.

- 19 A test made with both a balanced valve and an unbalanced valve, showed a decrease in friction of 23.9 per cent when using the balanced valve. This does not mean that the engine gained in power 23.9 per cent, but that the *friction load* of the engine was decreased almost one-quarter by the use of the balanced valve.
- 20 *Friction Losses in Piston Rod Packings.* The summary of a large number of tests made by Prof. Benjamin on piston rod packings, shows the following results: A soft rubber packing or a graphite packing consumes less power than packings of harder variety; proper lubrication of the piston rod reduces the friction with any packing; tightening up the packing nut may increase the friction loss to almost any amount.

LUBRICATION AND LUBRICANTS.

- 21 *Lubrication.* The objects of lubrication are as follows: First, to interpose a thin film or cushion of oil between the bearing surfaces, which will prevent them from actual contact with each other and cause one to glide easily over the other; second, to reduce the amount of friction and reduce the amount of power necessary to move the parts to the lowest possible limit; third, to prevent heating of the bearing surfaces by carrying off whatever heat is generated either with the running oil or by evaporation of the oil.
- 22 *Selection of a Lubricant.* The matter of the selection of a lubricant depends upon the character of the surfaces to be lubricated, the kind of machinery it is to be used on and the work the machinery is doing. In general, heavy ma-

chinery requires a thick, heavy oil and light machinery a light oil. The kind of oil required to lubricate the bearings of a watch would be obviously of little value for wagon axles, and an oil that might be entirely satisfactory for a wagon axle might, on the other hand, be of no value for the cylinder of a steam engine. Again, the steam engine cylinder oil would be positively harmful in a gas engine cylinder. Each class of machinery, therefore, and even different parts of the same machine, require an oil adapted to their especial needs in order to obtain the highest results from lubrication.

- 23 Most lubricants are easily adulterated and it requires the services of a well trained man to pass anything like competent judgment on an oil that he has not tried by actual use. For the young engineer, the best advice is to buy as good a grade of oil as can be obtained from a dealer whom he believes to be honest, and depend upon the dealer's honesty as to the quality of the goods purchased. Another thing, when a satisfactory brand of oil is found it is poor policy to change. It is better to stick to what is known to be all right, because at times considerable damage may be done with an inferior oil or one not adapted to the class of machinery being used.

- 24 *Properties of a Good Lubricant.* The value of a lubricant depends largely upon its *viscosity*, and this, in turn, depends somewhat upon the number of greasy particles it contains. A viscous oil is one that is syrupy and whose particles cling together when poured from the can. Usually the thick, heavy oils are most viscous, but this is not always

the case, as some cheap oils are treated to improve their viscosity in a manner which will presently be described. An oil should not contain either free acid or free alkali in excess. Almost all oil contains some acid, but those which contain 3 per cent or more should not be used, because the acid attacks the metal surfaces with which it comes in contact, and eats them away. A perfect oil is neutral, that is, it is neither acid nor alkaline. An oil should not be gummy, that is, it should not dry out but always remain in the same state of fluidity. It should not contain grit or dirt or any foreign substances. It should not solidify at ordinary low temperatures, and it should not become rancid or bad smelling when exposed to the air for a considerable length of time.

- 25 *Sources of Lubricants.* Lubricants may be classified according to their origin, as *animal*, *vegetable* and *mineral*. Animal oils are derived from the fats of animals and fishes, vegetable oils from the seeds and fruits of plants, and mineral lubricants from petroleum and certain rocks.
- 26 *Animal Oils.* The principal animal oils are lard oil, tallow oil, neats foot oil, whale oil, sperm oil, etc. Lard oil is the best animal oil for the lubrication of machinery. Its principal use is in lubricating the dies and taps for cutting threads, especially pipe threads. When applied to polished metal it has a tendency to rust the metal that mineral oils do not have. It is, however, a very good lubricant for medium sized bearings, but no good for cylinder and valve lubrication.
- 27 Tallow oil is obtained from tallow, being the lightest part

which rises to the top of melted tallow. It is a semi-liquid at ordinary temperatures and is a good lubricant. Tallow was for many years the principal lubricant for steam engine valves and cylinders, but at the present time it is used mainly for compounding mineral oils and is not used much in the clear state.

- 28 Neats foot oil is obtained by boiling the hoofs and bones of cattle, in water. The oil rises to the top and is drawn off. It is a good lubricant for bearings but finds its widest application as a harness oil, as a belt dressing, and in the treatment of leather. It is also used to some extent in compounding cylinder oils.
- 29 Sperm oil is obtained from the sperm whale and is very expensive. It is used for lubricating indicators, watches, clocks, etc.
- 30 *Vegetable Oils.* Among the various vegetable oils may be mentioned linseed oil, cotton seed oil, palm oil, castor oil, and corn oil.
- 31 *Linseed oil* is obtained from flax seed and finds its principal use in paints. It is useless as a lubricant because it dries quickly and forms a hard rubber-like crust.
- 32 *Cotton seed oil* is also of a drying nature and is consequently unfit for lubricating purposes. It is used as an adulterant for other vegetable oils and in cooking.
- 33 *Olive oil* is probably the best of the vegetable oils for lubricating machinery, although some of the others are good also. Its rather high price as compared with some of the animal and vegetable oils prevents its general use.
- 34 *Castor oil* is made from the castor bean and while it has a

tendency to become gummy it is nevertheless a very good lubricant for buggy and wagon axles.

- 35 *Mineral Oils* are obtained from the residue of crude petroleum after the illuminating oils have been distilled off. These oils are made in all grades, from the light water white paraffine oils, used on cream separators, to the heavy black oils, used for the roughest, heaviest kind of work. Mineral oils are used for lubrication more widely than any other class of oils, and when of the proper grade for the work in hand, are very satisfactory.
- 36 *Compounded Oils.* In addition to the three classes of oils just mentioned there are a good many brands of oil made by compounding one or more oils with the object of giving the oil so formed certain special characteristics, or, of blending several cheap varieties in such a way as to imitate a high grade product. Steam engine cylinder oils are almost always compounded oils, made by mixing together a mineral oil with either an animal or a vegetable oil. This is necessary because a purely mineral oil will not stick to a moist surface, while either an animal or a vegetable oil will; consequently, mixing mineral oil with the right proportion of either of the other oils yields a product which readily forms an emulsion with water and adheres to the cylinder walls, while at the same time retaining in a large measure the high heat resisting qualities of the pure mineral product.

TESTS OF OILS.

- 37 In order to determine the qualities of an oil, it is subjected to certain tests, which are intended to determine its specific

gravity, viscosity, flash point, burning point, congealing point, and its tendency to evaporate. Besides these, certain other tests are made to determine whether animal or vegetable oils are used in compounded oils.

- 38 *The Specific Gravity* of an oil or any other substance may be defined as the ratio between its weight and the weight of an equal volume of water. For example, a cubic foot of water weighs $62\frac{1}{2}$ pounds. If a cubic foot of oil weighs 58 pounds the specific gravity of the oil is equal to 58 divided by $62\frac{1}{2}$ or .928. In actual practice the specific gravity of an oil is determined by means of an instrument called an *hydrometer*, which consists of a glass tube weighted at the bottom with mercury. The stem of the instrument is graduated and when placed in the liquid to be tested, the weight sinks it to a certain depth, which may be read on the graduated stem. The depth to which it sinks depends upon the density or weight of the liquid, and so the specific gravity may be read directly.

- 39 *The Viscosity* of an oil is measured with an instrument called a *viscosimeter*. Viscosimeters are constructed in a variety of ways and are standardized either with pure water or with a solution of sugar and water of a known strength. The viscosity of oil, therefore, is compared with the viscosity of the standard solution just mentioned. Frequently a light grade of oil is mixed with paraffine or other waxes to improve its viscosity. Such an oil is not as good a lubricant as one that has the proper natural viscosity and in general should be condemned. To detect adulteration of this sort, put a spoonful or two of oil in a bottle containing about half

a pint of gasoline and let it stand for an hour or two. If any sediment appears in the bottom of the bottle it is evidence of adulteration to improve the viscosity.

- 40 *A Simple Test for Relative Viscosity.* A simple way to test the relative viscosity of several oils is to pour two or three drops of each oil to be tested on the end of a long level strip of glass. Then elevate the end of the glass on which the oil was placed about an inch and watch the oil race toward the lower end. The most viscous oil will move slowest. If the oil ends in a small drop of gum it proves that the oil is gummy and not fit to use in the bearings of machinery.
- 41 *The Flash Point* of an oil represents the temperature at which an inflammable vapor arises from the oil. The method of making the flash test is to heat the oil in an iron cup, in which a thermometer, reading to six or seven hundred degrees, is inserted and at frequent intervals passing a lighted taper just above the top of the cup. The temperature at which this vapor ignites, as shown by the thermometer, is called the *flash point* of the oil.
- 42 *The Burning Point.* The burning point of an oil is determined in the same way as the flash point and represents the reading of the thermometer when the oil itself will take fire and burn. These two tests are very important ones, especially for an oil that is to be used for valve or cylinder lubrication, or in places where it is subjected to a high temperature. The temperature of steam at 100 pounds gage pressure is 337° , as shown by the steam tables. Consequently an oil to be suitable for a cylinder oil in a cylinder

using steam at 100 lbs. pressure must have a flash test of at least 400°. With steam at higher pressure the flash point must be correspondingly higher. Most of the cylinder oils on the market have a flash point of 400° and upwards.

43 *The Cold Test* of an oil consists in finding the temperature at which the oil congeals or begins to solidify. In the case of cylinder oils, or other dense oils of high viscosity, it is the temperature at which the oil will just begin to flow after having been frozen. This test does not indicate the lubricating value of an oil, but it is essential that oil which is to be used on machinery exposed to cold weather shall show a good cold test, in order that it may flow freely. The cold test of an oil can be made by inserting a thermometer in a cup containing the oil, and then packing the cup in a mixture of cracked ice and salt.

44 *The Evaporation Test.* An oil that is to be used in a very warm place, such as for example in the main bearings of traction engines, should not evaporate or volatilize at ordinary working temperatures, because, when the lighter portions are driven off, that which remains will become very thick and increase the frictional resistance of the bearing. The test is rather difficult to make because it requires a very sensitive balance. As usually made, a small dish of oil is carefully weighed and then exposed to a temperature of about 150° for ten or twelve hours, and then weighed again. The difference between the first weight and the second weight will represent the amount that has evaporated. The best test for a traction engineer to make is to pour a small

quantity of the oil on the boiler near the bearings. If it smokes it is an indication that the oil vaporizes too easily, or, in other words, has too low a flash point for use on the main bearings.

45 *Test for a Compounded Oil.* To test if mineral oil has been mixed with either a vegetable or animal oil, fill a small bottle about one-third full of oil, then put in some caustic soda and water. Shake the bottle vigorously for a few moments and if the oil and water mix thoroughly, forming a brown emulsion, it is evident that either an animal or vegetable oil is present, because a pure mineral oil will not form an emulsion with water. There are numerous other tests for oils, which may be made in a well equipped laboratory that are valuable in determining their properties, but they are of little value in a work of this kind and are purposely omitted. The tests given above are not all easily made by an inexperienced man, but they are inserted here simply as an item of general interest.

46 The following table shows some of the properties of a number of the different oils:

TABLE I.

	Specific gravity.	Flash point.	Burning point.	Per cent of acid.
Linseed Oil	.933	.520	...	...
Cotton Seed Oil	.922	.365	...	...
Castor Oil	.964	.345	...	...
Rape Seed Oil	.914	.530	...	...
Olive Oil	.919	.450	...	...
Corn Oil	.922	.480	...	...
Neats Foot Oil	.915	.450	...	...
No. 1, Lard Oil	.912	.450	.530	2.90
Winter Strained Lard Oil	.915	.515	.640	2.90
Tallow Oil	.909	.560	...	...
Palm Oil	.904	.420	...	...
Extra Golden Mach. Oil	.890	.380	.530	2.40
Vacuum Dynamo Oil	.873	.380	.420	.21
Eldorado Oil	.889	.328	.390	4.9
600 K Oil	.901	.500	.600	1.4
600 W	.904	.540	.640	2.67
Capital Engine Oil	.932	.480	.520	1.31
Gas Engine Oil	.908	.400	.430	1.30

47 *Greases.* In general, it may be said that a grease or hard oil as it is frequently called, is not as good a lubricant as a fluid oil. Before a grease can act as a lubricant it must first become fluid, and this can only occur after the bearing has generated a certain amount of heat, thus showing that a certain amount of frictional resistance must have been overcome to heat the bearing. However, there are many places where greases are very convenient to use, and where the amount of friction over that necessary for a fluid oil makes practically no difference; as for example, the crank pin and cross head pins of traction engines, and numerous other places where the handiness and cleanliness of grease much more than offsets the small loss due to friction.

48 Greases are divided into two classes, known as axle grease and hard oil. Axle grease consists of a mixture of a low grade of animal or vegetable oil, which is treated with

lime, thus making a sort of insoluble soap. Some of these greases are then mixed with either mica or graphite. They are used principally for the axles of heavy vehicles and trucks, and for such purposes are very satisfactory.

49 *Hard oil* is made chemically from high grade materials and is in reality an insoluble soap which is subsequently softened with mineral oil. It is perfectly neutral, that is, containing neither acid nor alkali, and will keep for an indefinite period. Greases of this kind are very valuable for certain of the bearings in traction engines and separators, as for example the crank pin and cross head pins, before mentioned, and the cylinder boxes of separators.

50 *Solid Mineral Lubricants.* In addition to the oils and greases above mentioned, there are a number of dry or solid lubricants. These are graphite, soap stone, sulphur and mica. The best of these natural lubricants is graphite, known, also, as plumbago and black lead. It is a form of carbon and is mined in various places, notably along the shores of Lake Champlain in the United States, and also in various places in Canada and other countries. It is used for lubrication, either as flake or powdered graphite, and sometimes in the form of compressed bushings. Graphite will stand any degree of heat and is valuable in cut or roughened bearings. It is not as good a lubricant as oil, since it cannot run off from the bearing and carry away any heat, neither can it volatilize and carry away heat. All it can do is to reduce the amount of friction. When used sparingly and judiciously it is of great value, but it can not entirely take the place of oil or greases. It is frequently

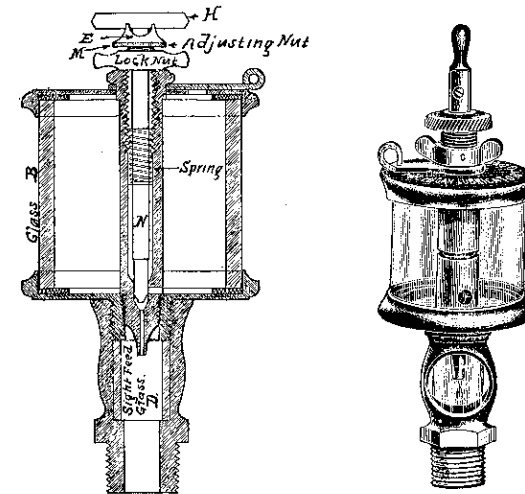
mixed with greases and is valuable on hot bearings to level up the inequalities of the rubbing surfaces.

- 51 When sulphur is used as a lubricant, it is used in the powdered form, known as flour of sulphur. It is also valuable on roughened bearings, but has no advantages over graphite.
- 52 Mica is a natural rock and is sometimes used for a lubricant in the powdered form, and sometimes compressed into bushings and used in place of brasses on light machinery.

LUBRICATORS.

- 53 *Classification.* The lubricators used on traction engines may be divided into two classes, namely; those especially adapted for the lubrication of bearings, such as main bearings, crank pin, wrist pin, etc., known as *bearing lubricators*, and those intended for the lubrication of surfaces in contact with steam, known as *cylinder lubricators*.
- 54 *Bearing Lubricators* may be subdivided into three more classes; plain lubricators, sight feed lubricators, and grease cups. Cylinder lubricators may also be subdivided into three classes; hydrostatic lubricators, water displacement lubricators, and pumps.
- 55 *Bearing Lubricators.* Plain lubricators and sight feed lubricators can be used only with oil. Grease cups are used for grease or solid oil. The simplest device for supplying oil to a bearing is a plain brass cup having a central tube extending up almost to the cover. One end of a few strands of candle wicking is inserted in this tube and the

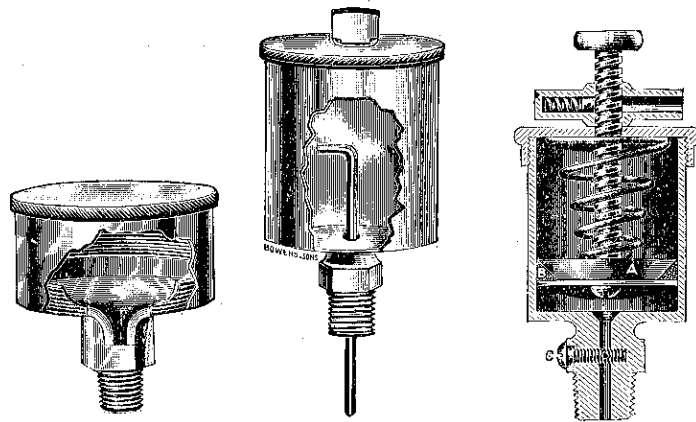
other end is allowed to dip into the oil. The wicking acts just like the wick in a lamp and supplies the bearing with oil. The objection to a lubricator of this kind is its uncertainty of action, and the lack of adjustment of the rate of the flow of oil. Other plain lubricators are made with a central



Sight Feed Lubricator. Fig. 256. Fig. 257.

tube, having a steel ball on the top which is held in place by a cap, screwed on the top of the tube. This form of lubricator will work only on bearings which work up and down rapidly, such as the crank pin. When the ball is thrown up from its seat by the vibration of the moving bearing, a drop of oil flows into the tube.

- 56 *Sight Feed Lubricators* are made in a variety of ways, but the general principle of their construction is well illustrated in Fig. 256. The oil reservoir B is a glass cylinder. This is surmounted by a snap lever H, attached to a needle valve N, which seats in the brass body of the valve below the glass cylinder. A spiral spring encircles the valve stem and holds it to its seat when the lever H is down in its seat E. When the lubricator is feeding, the lever H is raised to the position shown in the figure, compressing the spiral spring and holding the needle valve from its seat. The size of the opening through which the oil flows is regulated by the milled nut M. The feed of the



▲ Plain Grease Cup.
Fig. 258.

Fig. 259.

An Automatic
Grease Cup. Fig. 260.

oil can be observed through the glass disc D. A lubricator of this class, but of a slightly different pattern, is shown in perspective in Fig. 257.

- 57 *Grease Cups* are made in two styles, plain and automatic. Fig. 258 shows one style of plain grease cup. The illustration shows its construction plainly enough without further discussion. In order to make it feed, the top is screwed down by hand occasionally.

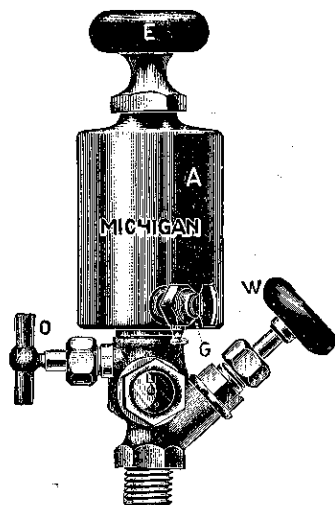
- 58 Another plain grease cup is illustrated in Fig. 259, in which a brass wire extends down through the oil and rests on the shaft. This conveys the heat from the shaft and melts the oil, causing it to flow down along side of the wire and into the bearing.

- 59 An *Automatic* grease cup appears in Fig. 260. It consists of a brass cylinder or grease cup, fitted with a plunger A, attached to a threaded stem passing up through the cover upon which is fitted a thumb nut. Screwing down this nut lifts the plunger and compresses the heavy spring between it and the cover. When the plunger is lifted in this way, the cover of the cup may be removed and the body filled with grease. To start the cup working, unscrew the thumb nut until it does not touch the cover. The spring will put pressure on the plunger and force the grease down into the bearing. When the engine is stopped the thumb nut should be screwed down until it seats firmly upon the cover. The screw below the grease chamber is provided with a hole which may be made to coincide with the opening through the stem or which may be turned slightly to regulate the flow of grease.

- 60 *Cylinder Lubricators* depend for their operation upon the difference in weight between oil and water, upon the pressure exerted by a column of water, or upon the action of a

pump operated either by hand or from some moving part of the engine.

- 61 *Water Displacement Lubricators* depend upon the first principle mentioned above and are very simple in construction as will be seen on referring to Fig. 261. The operation of the lubricator is as follows: The reservoir A is



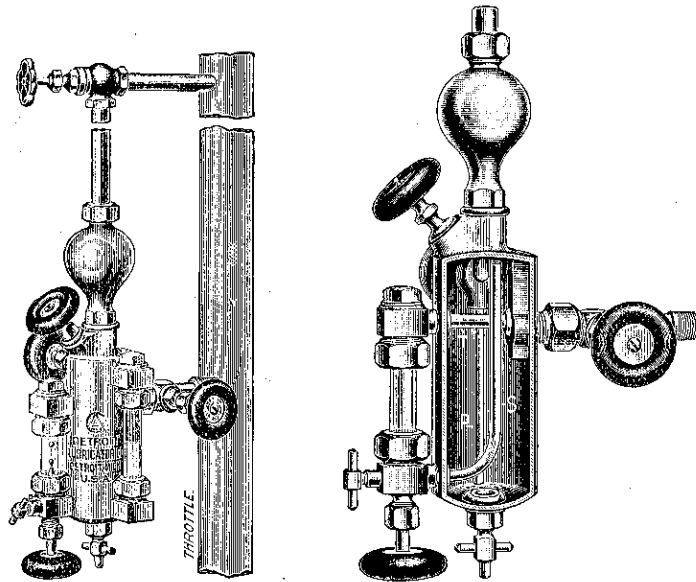
A Water Displacement Lubricator. Fig. 261.

filled with oil, and the plug E screwed in place. The valve W is then opened which allows steam to pass up through the central tube to the top of the lubricator, where it condenses by coming in contact with the cold surfaces of the oil and reservoir. Since water is heavier than oil, volume for volume, it sinks to the bottom and displaces an equal

amount of oil. This oil, having no other outlet, escapes down the central tube and flows into the steam chest and steam pipe.

- 62 Some lubricators of this type are provided with a sight feed glass in the stem below the regulating valve O, like the one in the figure, while others are not. When the engine is stopped, valves O and W should be closed or the lubricator will continue to work until empty. Lubricators of this type are sometimes placed on the steam chests of traction engines to be used only in case of accident to the oil pump or regular lubricator.
- 63 *Hydrostatic Lubricators*, as the name indicates, depend upon the pressure of a column of water for their operation. These lubricators are made in two general styles, *single connection* and *double connection*.
- 64 Double connection lubricators are provided with two pipes which connect them with the main steam pipe. One pipe admits steam to the lubricator, the other conveys oil from the lubricator to the steam pipe.
- 65 A well known make of double connection, hydrostatic lubricator is shown in Fig. 262. (a) being a side view and (b) a sectional view. The body of the lubricator A, is filled with oil. Steam enters from the steam pipe through the upper connection and condenses in the condenser A2, filling both it and part of the pipe above it with water. The water of condensation enters the bottom of the oil reservoir through pipe P. Steam also passes through pipe K and tube T to the sight feed glass H, filling it with water.
- 66 In order to start the lubricator, first open valve Ag and

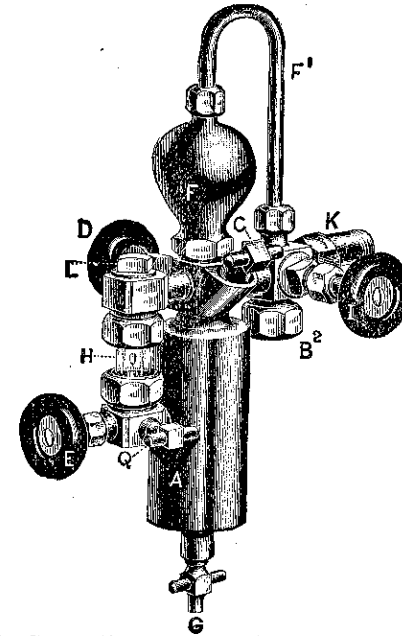
allow the glass to fill with water, then open Λ_4 which admits water from the condenser to the oil reservoir, and regulate the feed of oil by valve Λ_7 . The action of the



A Double Connection Hydrostatic Lubricator. Fig. 262.

lubricator is as follows: When the valve Λ_9 and the valve above the condenser are both opened, there is the same steam pressure acting at the upper connection as at the outlet K. So far as the steam pressure is concerned, therefore, there is no tendency for the oil to flow out of the lubricator. The weight of the column of water in the condenser and in the pipe above it, however, adds a little more pressure at

the upper connection than exists at the outlet K, and it is this force which sets the oil in motion. The column of water, due to its weight, flows down the pipe P to the bottom of the reservoir and displaces an equal volume of oil. Since the oil has no other point of egress, it flows down the



A Single Connection Hydrostatic Lubricator. Fig. 263.

pipe S and escapes from the oil nozzle at the bottom of the sight feed glass H. Here it forms in drops and being lighter than water floats up through the sight feed glass, and thence through the pipe T to the steam pipe. It is here

caught by the rapidly moving steam and carried to the steam chest and cylinder. On the way thence, if it is good steam engine oil, it is atomized or broken up into a fine spray and becomes intimately mixed with the steam.

- 67 *A Single Connection* lubricator is illustrated in Fig. 263. Connection is made with the steam main at K. Inside of pipe K there is a small brass tube which conveys the oil from the top of the sight feed glass, and delivers it into the current of steam flowing to the engine. Steam flows into the lubricator through connection K and then passes up through the brass equalizing tube F' to the condenser F. Here it condenses, filling the left leg of the loop and the condenser with water. The column of water which operates the lubricator extends from the top of the loop to the bottom of the reservoir A. The following description refers to the letters of the illustration:

DESCRIPTION.

- A—Oil Reservoir.
- B2—Connection for Attaching to Steam Chest.
- C—Filler Plug.
- D—Water Feed Valve.
- E—Regulating Valve.
- F—Condensing Chamber.
- F1—Equalizing Tube.
- G—Drain Valve.
- H—Sight Feed Glass.
- L—Plug to Insert Glass.
- K—Connection to Steam Pipe.
- Q—Drain Valve for Sight Feed Glass.
- I—Valve in Support Arm.

- 68 Figs. 264 and 265 represent another style of hydrostatic lubricator having a steam chamber within the oil reservoir which is intended to keep the oil at a scalding temperature even in severe weather. The steam connection is made between the boiler and the throttle and the discharge tube between the throttle and the engine.

- 69 Fig. 264 is a double connection lubricator and Fig. 265 a single connection. The following description refers to the letters on Fig. 264.

- H—Condenser Pipe.
- J—Oil Delivery Pipe.
- E—Filling Plug.
- K—Plug for Removing Glass.
- C—Water Regulating Valve.
- D—Sight Feed Glass.
- F—Drain for Glass.
- C—Oil Regulating Valve.
- G—Drain Valve.

- 70 Fig. 266 represents another style of hydrostatic lubricator which is much simpler in construction than either of the ones just described. While its principle of action does not differ from either of the others it has an entirely different sight feed. The condensed steam flows through a small tube and the water flows over a bright metallic plate behind the bulls eye glass, shown at the left of the illustration. From this point it runs down along the wall of the oil reservoir to the bottom, and displaces the oil which finds egress through a small tube at the top of the oil chamber which conveys it to the steam pipe. When in

operation one can see the drops of water enter the lubricator, but can not see the oil escape. Two valves control the working of the lubricator, and each should be opened about one-quarter of a turn. These lubricators are made with either one or two connections.

71 *Care of the Sight Feed Lubricator.* In connecting up a

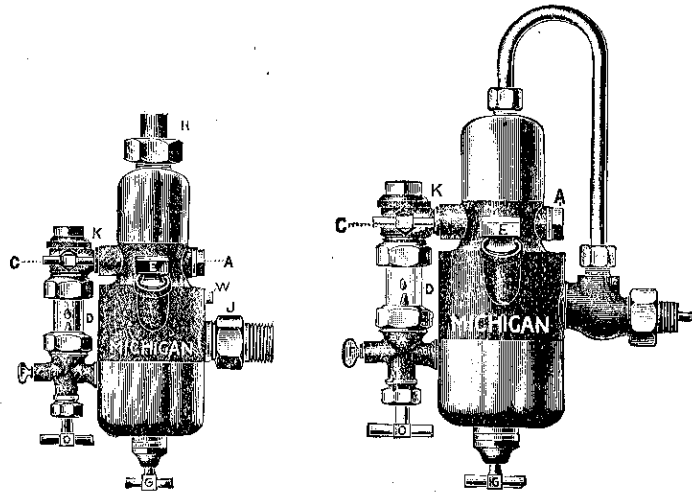


Fig. 264.

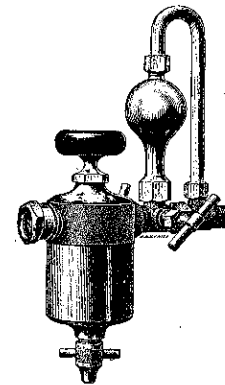
Fig. 265.

Hydrostatic Lubricators.

sight feed lubricator it is important that the oil delivery tube extend well inside the main steam pipe so that the drops of oil will be caught directly in the current of steam and be thus carried on to the cylinder instead of simply running down inside of the pipe as will be the case if the delivery tube is too short.

72 Another very essential thing in connection with lubricators is that all the joints be perfectly tight, otherwise a slight leak will cause a loss of pressure and thus destroy the effect of the head of water in the pipe above the lubricator.

73 The lubricator may fail to work for any one of the following reasons: Leaky joints; the clogging of the sight feed glass, due to foreign matter getting into the feed valve

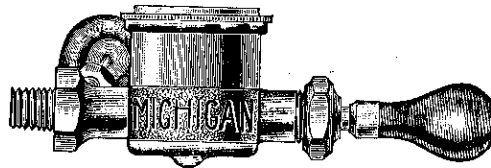


Single Connection Swift Lubricator. Fig. 266.

or into the discharge passage at the top of the lubricator. The packing of the sight feed glass may be squeezed out of the top of the glass or the oil nozzle at the bottom of the sight feed glass may be choked. It is a good plan, occasionally, to fill the lubricator full of kerosene oil and let it stand for several hours and thus loosen up the gummy oil or the dirt that may have accumulated in the passages. Before filling it again it should be blown out with steam.

74 If the lubricator is allowed to run empty the last few drops of oil often form in bubbles, due to being heated by the steam, and when they emerge from the oil nozzle at the bottom of the glass, break and strike against the sides of the glass; or, the top of the oil nozzle may be roughened or dented out of its proper shape, in which case the oil does not rise in drops as it should and so sticks on the inside of the glass, clogging it.

75 When trouble is experienced through the fouling of the glass, it should be cleaned out either with a bit of waste tied to the end of a splinter of wood or the oil nozzle examined



Hand Operated Oil Pump. Fig. 267.

to see that it is in proper shape. In cleaning a glass do not use a metal rod, because a slight scratch on the inside of the glass tube is almost sure to cause it to break.

76 One of the difficulties often experienced with sight feed lubricators is what is termed "churning." This is caused by not filling the oil reservoir completely full of oil and if there is not enough water in the condenser to make up the deficiency, the steam will enter the oil reservoir and cause the oil to boil and become foamy. Let it be remembered that in order for a lubricator to work at all the oil reservoir must be completely filled either with oil or with

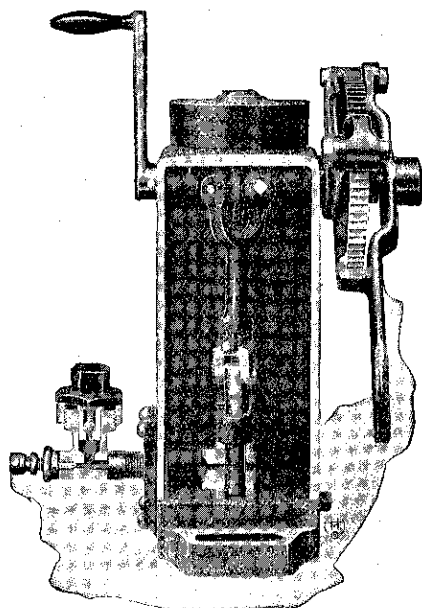
oil and water. When the engine is fired up in the morning, the valve leading to the condenser pipe should be opened to allow it to fill with water. If the steam is gotten up too high before this is done, the steam may heat the lubricator so hot that condensation will be very slow and difficulty will be experienced in getting the lubricator to start.

77 When the engine is shut down for any length of time, as for example at the noon hour, the oil regulating valve should be closed and the water feed valve left open. If this is not done the steam which enters the delivery pipe will heat the oil, causing it to expand and exert a heavy pressure on the body of the lubricator, which may be so great as to cause the lubricator to bulge or even to burst.

78 *Oil Pumps.* The simplest form of oil pump used to lubricate the cylinder of a traction engine is the hand pump, one form of which is shown in Fig. 267. Lubricators of this type are used only in case it becomes necessary to introduce quite a large quantity of oil into the cylinder in a short time, as for example after an engine has primed badly.

79 *Automatic Oil Pumps* are operated by some moving part of the engine, generally the eccentric rod in traction engines. They consist of a reservoir which contains the oil and a pump cylinder and plunger attached thereto. When the plunger is drawn backward oil fills the cylinder and on the next forward stroke it is forced out through the delivery tube into the steam pipe or steam chest. The action of an oil pump is positive and the amount of oil which it feeds to the engine at each stroke depends upon the size of the piston and the distance it travels.

- 80 Some oil pumps are constructed with the pump inside of the oil reservoir and others with the pump on the outside. Some have a steam pipe extending through the oil space to keep the oil warm and others depend upon the heat of the

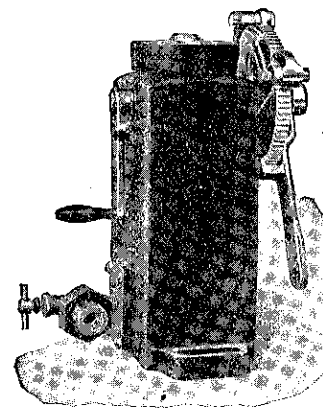


Internal View of Oil Pump. Fig. 268.

steam chest to keep the oil in a fluid condition. Some are provided with a sight feed and others are not. In one particular all oil pumps are alike in that motion is given to the crank which operates the pump plunger by means of a pawl

and ratchet wheel which receive their motion from a rod which is attached to some moving part of the engine.

- 81 Fig. 268 illustrates the internal construction and Fig. 269 shows a side view of a well known oil pump used widely on traction engines. In this style of pump the plunger is placed inside of the oil reservoir and receives its motion from the ratchet wheel and lever shown on the right, through

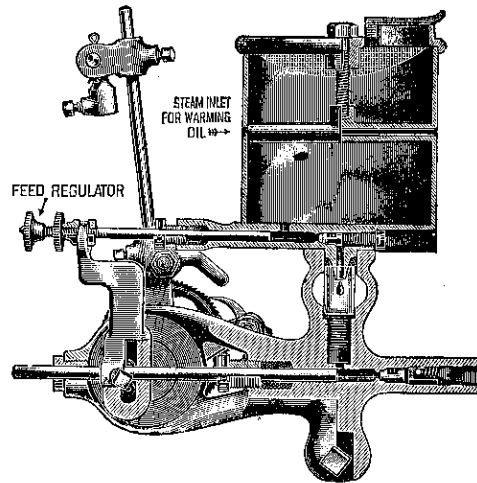


External View of Oil Pump. Fig. 269.

an eccentric mounted on the ratchet wheel shaft. This eccentric not only gives the plunger an up and down motion, but a rotary motion as well. The construction of the plunger is such that no check valves are necessary in the pump. A slot is sawed lengthwise of the plunger, beginning at the lower end and extending upward about an inch. When the plunger is on the up stroke, as shown in Fig. 264, this slot is turned toward the opening to the oil reservoir

and away from the delivery pipe. On the downward stroke the plunger is turned so that the slot comes opposite to the delivery port and closes the inlet port; thus the plunger acts itself as a check valve.

- 82 Oil pumps can be obtained with almost as many oil connections as desired, which will oil several cylinders or as is



Another Type of Oil Pump. Fig. 270.

the case in some gas engines, will oil not only the cylinders but the crank shaft bearings as well.

- 83 *Another Style of Oil Pump* is illustrated in Fig. 270. Here the pump is placed outside of the oil cylinder, a sight feed is provided and a steam pipe connection for warming the oil in cold weather. The feed of an oil pump may be

regulated by changing the length of the ratchet arm. When the ratchet takes only one cog of the wheel at a time, it is feeding the minimum amount of oil.

- 84 Some oil pumps make all of the adjustment at this point and others, like the one shown in Fig. 267, change the length of stroke of the plunger also.

- 85 *Advantages of Pump Lubricators.* It is positive and certain in action and feeds only when the engine runs. When the engine stops the lubricator stops without any effort on the part of the engineer, and when the engine starts the pump starts, thus making for convenience.

- 86 Since it does not depend upon water for its action, it is without danger of freezing and does not require attention every night to see that it is properly drained.

- 87 *The Care of Oil Pumps.* Oil pumps that are not provided with a warming pipe should be placed on the steam chest where the heat is sufficient to keep the oil in a fluid condition even in severe weather. Where a cross compound traction engine is to be lubricated, better results will generally be obtained with a double connection pump which feeds to both cylinders, than with a single connection lubricator that feeds only to the high pressure cylinder. The reason for this becomes apparent when one considers that the low pressure cylinder is much larger than the high, and consequently requires more oil. If enough oil were introduced into the high pressure cylinder for both, it would be flooded with oil, while if barely enough were used for the small cylinder the low pressure would not have enough oil.

QUESTIONS FOR PART XIII.

1. Define friction.
2. State the five principles of friction.
3. Mention some of the beneficial effects of friction.
4. Explain the coefficient of friction.
5. How are the friction losses in an engine distributed?
6. Name the objects of lubrication.
7. Name at least three properties of a good lubricant.
8. Mention the sources of lubricants.
9. For what purposes are the following named oils adapted: Lard oil, tallow oil, neatsfoot oil, cotton seed oil, castor oil, and sperm oil?
10. Why are oils compounded?
11. To what tests are oils subjected?
12. Explain the flash test.
13. How do hard oils or greases compare with fluid lubricants?
14. Mention three solid lubricants, and explain what they are used for?
15. How may lubricators be classified?
16. How are steam lubricators classified?
17. Upon what three principles do steam lubricators work?
18. Describe three different styles of grease cups.
19. What precautions should be taken in connecting up a sight feed lubricator?

20. Name several reasons why sight feed lubricators may fail to work.
21. What is meant by the term "churning" as applied to a lubricator?
22. What are hand oil pumps used for?
23. How are automatic oil pumps operated?
24. Name some of the advantages of pump lubrication.

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LESSON WITH QUESTIONS

STEAM TABLES, HEAT, ETC.
PART XIV

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LESSON WITH QUESTIONS

PART XIV

STEAM TABLES, HEAT, ETC.

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

LESSON XIV.

THE NATURE OF HEAT, STEAM TABLES, ETC.

- 1 *Introduction.* In all considerations of the steam engine, gas engine, or other form of engine which depends upon fuel for its motive power, the problem of first importance is to transform the greatest possible amount of heat energy into work. For this reason it is necessary to study the phenomena of heat in order to thoroughly understand an engine and appreciate how heat may be transformed into mechanical energy.
- 2 In order that an engine may be able to run and generate power, heat must first act upon some substance which will absorb a certain amount of heat energy, and then be passed through the engine where this energy is transformed into work. In the case of the steam engine water is the medium used. This is first transformed into steam and the steam is made to do work in an engine cylinder at the expense of the heat it contains. Gas or oil engines, on the other hand, use air and the gases which arise from the combustion of the fuel as the medium upon which the heat acts.
- 3 It is the purpose of the present lesson to discuss the laws of heat in a simple manner, to show how heat and work are related, and how heat energy is changed to mechanical energy in the steam engine.
- 4 *Heat.* Heat is a condition or effect, not a substance, as

STEAM TABLES, HEAT, ETC.

- it was formerly thought to be. If one pound of cold iron be heated to redness, it will still weigh just one pound, neither more nor less. Since the addition of heat to the iron does not increase its weight, it shows that heat is not a material substance but, as stated above, is only an effect.
- 5 Sir Humphrey Davy melted two pieces of ice by rubbing them together, from which he concluded that heat was caused by motion. However, it is well known that substances may be heated without being moved appreciably, as for example the iron just mentioned. In order that the idea of motion be made to apply in every case, it must be assumed that if heat is motion, it must exist in parts of the body too minute to be seen.
 - 6 Each substance is supposed to be made up of molecules, that is, very minute particles which are bound together by some sort of mutual attraction or adhesion. These molecules are supposed to be in a continual state of agitation, which varies with the degree of temperature. If by any means these molecules can be made to vibrate more rapidly the temperature will increase correspondingly. This seems proven in the case of iron, where by hammering it rapidly it may be heated even to redness, or in the case of a drill boring a piece of metal, the molecules of both drill and metal are heated by the rapid motion and heat is generated.
 - 7 From what has been said it appears that heat is a form of energy or work, and it may be inferred that heat and work bear a fixed relation to each other, that is, that a definite amount of heat may be changed into a definite quantity

of work, or *vice versa*, and such has been actually proven to be the case as will presently be shown.

- 8 *Temperature* and heat are not the same, although we commonly speak of them as if they were. Temperature denotes merely the intensity or degree of heat but not the *quantity*. For example, a cupful of water at 200 degrees

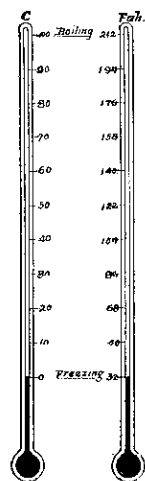


Fig. 271.
Thermometers.

is hotter than a barrelful at 100 degrees, as would be shown by a thermometer, but the barrelful contains much more heat and would melt a larger piece of ice than the cupful. A thermometer measures the *intensity* of heat but can not measure the *quantity*. In order to measure the quantity

of heat a body contains it is necessary to take into account not only its temperature but its weight and its capacity for absorbing heat.

- 9 *Thermometers.* Thermometers are instruments for measuring the intensity of heat. They consist, generally, of a glass tube containing a small cistern of mercury at the lower end (see Fig. 271). The diameter of the tube leading up from the mercury is very small, and a vacuum exists in the tube above the mercury. The working principle of a thermometer depends upon the fact that when a body is heated it expands an equal amount for equal additions in temperature. When the mercury in the cistern is heated it expands and is forced up the tube a distance proportional to the intensity of the heat.

- 10 There are two kinds of thermometers in quite common use in this country, the Fahrenheit and the Centigrade. The temperature of boiling water on the Fahrenheit scale is taken at 212 degrees, and on the Centigrade scale at 100 degrees. The temperature of freezing water on the Fahrenheit scale is 32 degrees and on the Centigrade scale zero. The space between 32° and 212° on the Fahrenheit scale is divided into 180 equal parts, while that on the Centigrade scale is divided into 100 equal divisions, thus making the value of a degree Fahrenheit, equal to $100/180$ or $5/9$ of a degree Centigrade. The Centigrade thermometer is used in all scientific work and the Fahrenheit thermometer for common use and in steam engineering.

- 11 *Absolute Temperature.* Just as we start with zero in counting, or with zero in measuring absolute pressure, so

for scientific purposes, we must start with zero in measuring temperature; that is, we must start at a point where there is absolutely no heat. A little consideration will make it evident that neither the Fahrenheit nor the Centigrade thermometers start measuring temperature at the absolute zero, because it is very easy to obtain temperatures much lower than the zero on either of these thermometers. Consequently those zero points are at a considerably higher temperature than other temperatures we are acquainted with.

- 12 Temperature, at any rate, is only relative. We say, when it is 10 degrees below zero, that it is cold; when it is 40 degrees below zero it is very much colder, and 10 degrees below zero as compared with 40 degrees below, is quite warm. On the other hand, when it is 100 degrees out of doors, we are accustomed to say it is very hot, but compared with temperatures in the furnace under a steam boiler, 100 degrees is very cold.

- 13 It has been found that if a cubic foot of air at zero degrees Fahrenheit be cooled one degree it will shrink $1/461$ part of itself. If it be cooled two degrees it will shrink $2/461$ parts of itself, and so on. It is evident that if it be cooled 461 degrees that its volume would shrink to nothing, if such were possible, and that all heat would cease to exist. It must be borne in mind, of course, that the above is only a theoretical consideration and is true only for an ideal gas, that is, a gas which is not actually a substance at all. The notion, however, has this value: it fixes a point for absolute cold or absolute zero, where absolutely no heat exists. At such a temperature the air would be frozen solid,

all of the water on the earth would be solid ice and absolutely no life could exist.

- 14 The temperature of 461 degrees below zero on the Fahrenheit scale, or 273 degrees on the Centigrade scale, is called the point of absolute zero. In order to change the temperature reading on the Fahrenheit scale to absolute temperature, all that is necessary to do is to add 461 to the reading of the Fahrenheit thermometer. For example, if it is 70° on the Fahrenheit scale, the absolute temperature is 70 plus 461, or 531 degrees. The practical use of this conception of temperature is found in scientific work and in cases where it is necessary to make careful and exhaustive tests of steam engine performance.
- 15 *A Heat Unit.* The unit for measuring *quantity of heat* is called the *British Thermal Unit*, or, as it is usually written, simply B. T. U. A heat unit is equal to the quantity of heat necessary to raise one pound of water through one degree Fahrenheit. If one pound of water be raised through 10 degrees it will require the expenditure of 10 thermal units, or, if 10 pounds of water be heated through 20 degrees, it will require 10×20 or 200 heat units.
- 16 Water is taken as a basis of comparison in measuring heat because it is the most common substance and because it requires more heat to raise it through a certain range of temperature than almost any other substance.
- 17 *Specific Heat* may be defined as the ratio of the amount of heat necessary to heat one pound of any substance one degree to the amount of heat necessary to heat one pound of water one degree.

- 18 The amount of heat that it would require to heat one pound of water one degree would heat one pound of copper about 10 degrees, consequently the specific heat of copper is $1/10$ —nearly.
- 19 The following table gives the specific heats of a number of the common metals and an inspection of it will show that each of them differs from all the others in its power to absorb heat.

TABLE I.

TABLE OF SPECIFIC HEATS.

Cast Iron	.1298
Lead	.0314
Silver	.0570
Tin	.0562
Copper	.0951
Zinc	.0956
Hard Steel	.1175
Soft Steel	.1165

- 20 The preceding table shows that if one pound of cast iron be heated one degree it will contain only .1298 of a heat unit, while under the same conditions a pound of lead will contain only .0314 of a heat unit. In other words it takes a smaller quantity of heat to heat lead through a certain number of degrees than any other substance mentioned in the table. This shows that lead is a good conductor of heat. Copper is also a good conductor—better than iron, and for

this reason it has been used in constructing fire boxes of locomotives on the theory that heat could pass more readily into the feed water.

- 21 *The General Effect of Heat.* The general effect of heat on any substance is to cause it to expand. The amount of expansion is directly dependent upon its change in temperature, and is equal for equal changes in temperature. In general, it may be said that solids expand less for a given change in temperature than liquids, and liquids less than gases. The fraction of its length which any substance expands for an increase of one degree in temperature is called the *co-efficient of expansion* of that substance. The following table shows the linear co-efficients of expansion of a number of the common materials used in engineering work.

TABLE II.

Name of Substance.	Amount of Expansion Due to a Change of 1 Degree Fah.
Wrought iron	.00000678
Tempered steel	.00000702
Cast iron	.000006172
Copper	.000009544
Brass	.00001037
Tin	.00001410
Aluminum	.000012850
Lead	.000015875
Zinc	.000016340

- 22 *Explanation of the Table.* If a bar of wrought iron be

heated one degree it will expand an amount equal to .00000678 of itself. This appears to be a small amount—hardly worth considering, and yet it must be taken account of in all structures into which iron enters. In the case of long runs of steam pipe where the change in temperature may be 200 degrees or more, slip joints, or expansion joints of some sort must be provided or the expansion of the pipe will cause it to twist out of shape or break its connections. It must be borne in mind that it would require just as much force to prevent a bar from lengthening, due to an increase in temperature, as it would to stretch the bar if force were applied to the two ends. In laying steam pipes it is customary to provide for two inches of expansion for every hundred feet. This amount is somewhat too high, as can be proven by a little calculation, but it provides a margin of safety which is demanded in all engineering work.

- 23 Copper and brass expand more than iron, which accounts for the fact that a brass valve or plug screwed into a boiler may fit fairly loose when cold, but will be exceedingly tight when the boiler is hot.
- 24 Illustrations of the expansion or contraction of metals can be observed in the case of telephone or telegraph wires. During the hot days in summer they are quite slack, but in winter when the days are cold they often contract enough to break.
- 25 *Example:* How much will a copper telephone wire twenty miles long expand if the weather changes from 20 degrees below zero to 100 degrees above?

- 26 *Solution:* $5280 \times 120 \times .000009544 = 6.047$ feet, the expansion in one mile. A telephone line twenty miles long would therefore change in length between winter and summer temperatures, $20 \times 6.047 = 120.94$ feet.
- 27 *The Effect of Heat on a Gas* is either to cause it to expand, if the pressure upon it remains constant, or, if it be imprisoned, to increase its pressure. For example, suppose



Fig. 272.

we have a cylinder fitted with a piston having an area of 50 square inches which weighs 500 pounds. Suppose the space A, below the piston, Fig. 272, be filled with gas. The pressure on each square inch, due to the weight of the piston, is ten pounds. If heat be now applied to the cylinder the pressure will remain constant, but the gas will expand and lift the piston upward. If, on the contrary, the

piston were fastened in its original position and heat were applied as before, the pressure exerted on the piston by the gas would increase indefinitely as long as heat was added.

28 *The Law of Charles.* The *volume* of a gas at constant *pressure* or the *pressure* of a gas at constant *volume* varies directly as the *absolute* temperature.

29 *Example I.* Suppose a certain volume of gas at a temperature of 100 degrees Fah. is under a pressure of 60 pounds absolute; what will the pressure be when the gas is heated to 200 degrees?

30 *Solution:* $100^{\circ} + 461^{\circ} = 561^{\circ}$ absolute temperature.
 $200^{\circ} + 461^{\circ} = 661^{\circ}$ absolute temperature.
 $60 \times \frac{661}{561} = 70.7$ pounds, nearly.

31 *Example II.* Suppose in Fig. 272 that the volume of the gas under the piston is two cubic feet when the temperature is 100 degrees Fah.; what will it be when the temperature increases to 200 degrees?

32 *Solution:* $100^{\circ} + 461^{\circ} = 561^{\circ}$
 $200^{\circ} + 461^{\circ} = 661^{\circ}$
 $2 \times \frac{661}{561} = 2.356$ cubic feet.

33 This explains why a bicycle tire when pumped up hard and stood out in the hot sun will often explode. The increase in pressure due to the change in temperature often amounts to several pounds. This law also explains why superheating steam will raise its pressure.

34 *The Mechanical Equivalent of Heat.* The exact relation between heat and work was first determined experimentally by Dr. Joule in England in 1854. His experiments showed that one heat unit is equivalent to 772 foot pounds. Some years later Dr. Rowland of the United States, with better facilities to work with, found the value of a heat unit to be 778 foot pounds. This value is the one at the present time accepted by all American engineers.

35 It seems almost inconceivable that the heat energy necessary to raise one pound of water through one degree Fah. should be equal to lifting 778 pounds one foot high, yet such is the case.

36 *Problem III.* How many foot pounds of work are equivalent to the heat energy necessary to raise one gallon of water from the freezing to the boiling point?

37 *Solution:* $212 - 32 = 180$ heat units added to the water.
 $8 \frac{1}{3}$ pounds—the weight of one gallon of water.
 $180 \times 778 = 140040$, the number of foot pounds of work equivalent to heating one pound of water from the freezing to the boiling point.
 $140040 \times 8 \frac{1}{3} = 1167000$ foot pounds, Ans.

38 The heat energy necessary to change one gallon of water from the freezing point— 32° F. to the boiling point— 212° Fah., is equivalent to lifting a mass weighing 1167000 pounds one foot high, or, of lifting 1167 pounds 1000 feet high. Such figures are too large to be easily comprehended, yet they are unquestionably true, as has been proven time and again. It is upon this conception of heat, more-

over, that all the theories of steam engineering are based.

39 *Rule I.* To change heat units into foot pounds multiply by 778.

40 *Rule II.* To change foot pounds into their equivalent in heat units, divide by 778.

41 *Example:* How many heat units are equivalent to one horse power?

42 *Solution:* A horse power is equal to 33000 foot pounds of work per minute; therefore, 33000 divided by 778 = 42.416, the equivalent number of heat units.

43 *The Boiling of Water.* If heat be applied to water in an open dish its temperature will begin to rise and the water will expand somewhat. When the temperature reaches about 200 degrees or a little more, bubbles will begin to form on the sides and bottom of the vessel. These will finally rise to the surface and break. The water is now said to be *simmering*, and the bubbles are formed by the air which the water contains. When the temperature reaches 212 degrees the water first actually begins to boil and bubbles of steam form on the bottom and rise to the surface and break, causing the agitation of the water known as boiling. If heat be applied further the temperature will remain *constant* at 212°, but steam will continue to form and escape from the dish until all of the water has been converted into steam. It is impossible to heat water in an open dish, under atmospheric pressure, hotter than 212° Fah., or 100 degrees Centigrade.

44 The boiling point of water is the point at which steam begins to form, and this temperature depends upon the

pressure exerted on the surface of the water. If the pressure is less than atmospheric pressure—that is, less than 14.7 pounds per square inch, water will boil at a much lower temperature. If, on the contrary, the pressure is greater than atmospheric pressure, as it is in a steam boiler under pressure, then the boiling temperature will be higher, as shown by the steam tables on another page of this lesson. For example, at 100 pounds absolute pressure the boiling point is at a temperature of 327.6 degrees.

45 *The Heating of Water in a Boiler.* If water in a closed boiler, having a space above for the accumulation of steam, be heated, steam will, if there is no air in the boiler, begin to form at once and it will keep on forming as long as heat is supplied, provided the strength of the boiler is not exceeded. The temperature, pressure, and weight per cubic foot of the steam will also continue to increase, and will bear a fixed relation to each other as will be shown in the steam tables.

46 If the heat supplied is just sufficient to maintain the temperature constant, the pressure and weight per cubic foot of the steam will also remain constant and the formation of steam will cease. If a steam pipe leading from the boiler be opened, however, steam will immediately flow out and momentarily reduce the boiler pressure, thus causing steam to begin to form again. So long, however, as the proper amount of heat is supplied to maintain a *constant* temperature, the boiler pressure will remain constant in a boiler supplying steam to an engine.

47 *The Formation of Steam.* Suppose one pound of water

be placed in the bottom of a cylinder of indefinite length as shown in Fig. 273, and suppose a piston having no weight and moving without friction in the cylinder be placed on top of the water, the diameter of the cylinder being such that the area of the piston is just one square foot. If the top of the cylinder be open the piston will be under atmospheric pressure.

- 48 Suppose the water be at a temperature to begin with of 32 degrees F., that is, just at the freezing point. If heat be applied to the bottom of the cylinder, the temperature im-

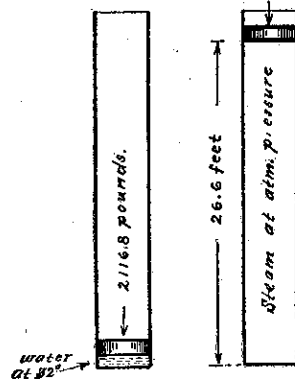


Fig. 273.

mediately begins to rise and will continue to rise until the water reaches 212 degrees. After this temperature is reached there will be no further rise in temperature, but steam will begin to form and raise the piston until, when

the water is all evaporated, the piston has risen to a height of 26.6 feet (see Column VIII. of the Steam Tables).

- 49 The area of the piston is 144 square inches and since each square inch bears a load of 14.7 pounds, the total resistance overcome by the piston is $144 \times 14.7 = 2116.8$ pounds.

- 50 Careful experiments show that it requires about 966 heat units to transform boiling water into steam at atmospheric pressure. After the water reaches the boiling point its temperature does not increase, but nevertheless it absorbs a large amount of heat. Since this heat cannot be measured by a thermometer it is called *latent heat*, that is, *hidden* heat.

- 51 The total amount of heat absorbed by the pound of water in changing from the freezing to the boiling point, and then into steam at atmospheric pressure, is $180 + 966 = 1146$ heat units.

- 52 The 966 heat units of latent heat have done two things; first, they have converted all of the water into steam, and, second, they have lifted the piston against atmospheric pressure through a distance of 26.6 feet, thus doing considerable work which we will call *external* work to distinguish it from the work necessary merely to change the water into steam without overcoming any resistance. This latter we will call *internal* work.

- 53 The amount of the external work in foot pounds is equal to the total weight on the piston, multiplied by the distance through which it moves, or, expressed in figures, it is $2116.8 \times 26.6 = 56306.88$ foot pounds. This quantity may

be changed to an equivalent number of heat units as follows: $56306.88 \div 778 = 72.37$ heat units.

- 54 Since the total latent heat is equal to 966 heat units, and 72.37 must be expanded in lifting the piston, the difference or 893.63 heat units must be what is required to change the water into steam, that is, to break up the molecules of the water. The total heat in the pound of steam may, therefore, be accounted for as follows:

180 heat units to change the water from 32 to 212°,
893.63 units to do the internal work,
72.37 units to do the external work,

1146.00 the total heat in one pound of steam at atmospheric pressure.

- 55 *Effect of Increasing Steam Pressures.* Under different pressures the total heat, internal work, and external work differ from what it is at atmospheric pressure, but in every case the internal work is very large and the external work proportionately small. For example, let us consider what these values are for steam at 100 pounds absolute pressure. To do this we will add enough weight to the piston to make the total weight to be moved equal to 100 pounds per square inch. Now, referring to the steam tables, we find that the total heat of steam at this pressure is 1182.0 heat units. The temperature of the water must be 327.7 degrees before steam begins to form at this pressure, therefore it will require $327.6 - 32$ or 295.4 heat units to heat the pound of water to the boiling point. (On the Fahrenheit scale the heat units are measured from 32 degrees up.)

- 56 The volume occupied by the one pound of water when changed to steam is 4.4 cubic feet. In the cylinder shown in Fig. 273 the piston will rise 4.4 feet in order to have space for that volume of steam underneath, because the area of the piston is just one square foot.

- 57 The area of the piston is 144 square inches and each square inch is under a pressure of 100 pounds, consequently the total pressure on the piston is $100 \times 144 = 14400$ pounds.

- 58 The weight moves 4.4 feet so that the external work done is $14400 \times 4.4 = 63360$ foot pounds.

- 59 $63360 \div 778 = 81.45$ the equivalent number of heat units used in external work.

- 60 $1182 - 295.6 = 886.4$ heat units, the internal and external work combined.

- $886.4 - 81.45 = 804.95$ the heat units used in external work.

- 61 To sum up we have:

295.60—heat units required to raise the water from the freezing to the boiling point.

804.95—heat units required in internal work.

81.45—heat units required to do external work.

1182.00—Total number of heat units in the one pound of steam at 100 pounds pressure.

- 62 It should be understood that the maximum amount of work which one pound of steam is able to do at any given pressure, if used in an engine *full stroke*, is exactly equal to the external work done during formation. This presupposes that the steam exhausts into a perfect vacuum, and

that there are no friction losses or heat losses at any point during the various changes.

63 *Percentage of Heat Turned Into Useful Work.* At atmospheric pressure the total heat is 1146 heat units, of which 72.37 heat units did useful work; reducing this to per cent we have $72.37 \div 1146 = 6.31\%$. Therefore of all the heat put into the steam only 6.31% did useful work. In the case of steam at 100 pounds pressure the total heat is 1182 heat units, of which 80.33 heat units were applied in external work; reducing this to per cent as before we have: $80.33 \div 1182 = 6.88\%$ applied in useful work.

64 These results show that the percentage of heat used in doing external work is just about the same with low pressure steam as with high pressure. Or, looked at in another way, it proves that if we use steam full stroke in an engine cylinder there can be practically no gain in economy made by increasing the pressures. There will, of course, be a gain in power, but this gain, whatever it may be, will require a correspondingly increased amount of steam and of fuel.

TABLE III.

Table of the Properties of Saturated Steam.

I	II	III	IV	V	VI	VII	VIII
Absolute pressure in pounds per square inch.	Temperature of the boiling point in degrees Fah.	Total heat above 32° F. in heat units	Latent heat in heat units	Heat expended in external work in heat units.	Heat expended in internal work in heat units	Weight of a cubic foot of steam in pounds.	Volume occupied by a pound of steam in cubic feet
1	102.2	1113.1	1043.0	61.9	981.1	.00299	334.6
2	126.3	1120.5	1026.1	64.2	961.9	.00576	173.6
3	141.6	1125.1	1015.3	65.8	949.5	.00844	118.4
4	153.1	1128.6	1007.2	66.8	940.4	.01107	90.31
5	162.3	1131.5	1000.8	67.7	933.1	.01366	73.22
6	170.1	1133.8	995.2	68.5	926.7	.01622	61.67
7	176.9	1135.9	990.5	69.1	921.4	.01874	53.37
8	182.9	1137.7	986.2	69.7	916.5	.02112	47.07
9	188.3	1139.4	982.5	70.1	912.4	.02374	42.13
10	193.2	1140.9	979.0	70.6	908.4	.02621	38.16
11	197.8	1142.3	975.8	71.0	904.8	.02866	34.88
12	202.0	1143.6	972.9	71.4	901.5	.03111	32.14
13	205.9	1144.7	970.1	71.7	898.4	.03355	29.82
14	209.6	1145.8	967.5	72.0	895.5	.03600	27.79
14.7	212.0	1146.6	965.8	72.3	893.5	.03758	26.64
16	216.3	1147.9	962.8	72.8	890.0	.04067	24.59
17	219.4	1148.9	960.6	73.0	887.6	.04307	23.22
18	222.4	1149.8	958.5	73.2	885.3	.04547	22.00
19	225.2	1150.7	956.6	73.4	883.2	.04786	20.90
20	227.9	1151.5	954.6	73.6	881.0	.05023	19.91
22	233.5	1153.0	951.0	74.0	877.0	.05495	18.20
24	237.8	1154.4	947.6	74.4	873.2	.05966	16.76
26	242.2	1155.8	944.6	74.7	869.9	.06432	15.55
28	246.4	1157.1	941.7	75.0	866.7	.06899	14.49
30	250.3	1158.3	938.9	75.3	863.6	.07360	13.59
32	254.0	1159.4	936.3	75.6	860.7	.07821	12.73
34	257.5	1160.4	933.7	75.9	857.8	.08280	12.07
36	260.8	1161.5	931.4	76.2	855.2	.08735	11.45
38	264.1	1162.5	929.1	76.3	852.8	.09191	10.88
40	267.2	1163.3	927.0	76.6	850.2	.09645	10.37

TABLE III.

THE PROPERTIES OF SATURATED STEAM.

I Absolute pressure in pounds per square inch.	II Temperature of the boiling point in degrees Fah.	III Total heat above 32° F. in heat units.	IV Latent heat in heat units.	V Heat expended in external work in heat units.	VI Heat expended in internal work in heat units.	VII Weight of a cubic foot of steam in pounds.	VIII Volume occupied by a pound of steam in cubic feet.
42.....	270.1	1164.1	925.0	76.8	848.0	.10090	9.91
44.....	272.9	1165.3	923.1	77.1	845.9	.10540	9.48
46.....	275.7	1166.0	921.0	77.2	843.8	.10990	9.10
48.....	278.3	1166.8	919.1	77.6	841.7	.11440	8.74
50.....	280.9	1167.6	917.4	77.7	839.6	.11880	8.41
52.....	283.4	1168.4	915.7	77.9	837.6	.12330	8.11
54.....	285.8	1169.0	914.0	78.1	836.0	.12772	7.83
56.....	288.1	1169.8	912.2	78.4	834.0	.13210	7.57
58.....	290.4	1170.5	910.3	78.5	832.3	.13660	7.32
60.....	292.6	1171.2	909.3	78.6	830.7	.14100	7.10
62.....	294.7	1171.8	907.7	78.7	829.0	.14530	6.89
64.....	296.8	1172.4	906.3	78.9	827.3	.14970	6.68
66.....	298.8	1173.1	904.6	79.1	825.6	.15400	6.49
68.....	300.8	1173.6	903.4	79.3	824.1	.15840	6.31
70.....	302.8	1174.3	902.0	79.4	822.8	.16300	6.14
72.....	304.7	1175.0	901.0	79.5	821.0	.16710	5.90
74.....	306.5	1175.4	899.5	79.6	819.7	.17140	5.83
76.....	308.3	1176.0	898.1	79.9	818.4	.17580	5.69
78.....	310.1	1176.5	897.0	80.	816.8	.1800	5.55
80.....	312.	1177.0	895.5	80.	815.5	.1843	5.43
82.....	313.5	1177.5	894.5	80.2	814.2	.1887	5.30
84.....	315.2	1178.0	893.2	80.3	812.8	.1930	5.20
86.....	317.0	1178.6	892.0	80.4	811.4	.1972	5.07
88.....	318.5	1179.0	890.8	80.5	810.2	.2016	4.97
90.....	320.0	1179.5	889.7	80.6	809.0	.2059	4.86
92.....	322.0	1180.0	888.4	80.8	807.6	.2101	4.65
94.....	323.0	1180.5	887.3	81.0	806.4	.2143	4.67
96.....	325.0	1181.0	886.3	81.1	805.2	.2187	4.57
98.....	326.	1181.4	885.0	81.2	804.0	.2230	4.49
100.....	327.6	1182.0	883.9	81.3	802.7	.2270	4.40
105.....	331.1	1183.0	881.2	81.4	800.0	.2380	4.21
110.....	334.6	1184.0	878.7	81.7	797.2	.2480	4.03
115.....	337.9	1185.0	876.2	82.0	794.4	.2590	4.87

I Absolute pressure in pounds per square inch.	II Temperature of the boiling point in degrees Fah.	III Total heat above 32° F. in heat units.	IV Latent heat in heat units.	V Heat expended in external work in heat units.	VI Heat expended in internal work in heat units.	VII Weight of a cubic foot of steam in pounds.	VIII Volume occupied by a pound of steam in cubic feet.
120.....	341.0	1186.0	873.9	82.1	792.0	.2700	3.71
125.....	344.1	1187.0	871.5	82.3	789.4	.2800	3.57
130.....	347.1	1187.7	869.4	82.5	787.0	.2900	3.44
135.....	350.0	1188.7	867.2	82.6	784.9	.3010	3.23
140.....	353.0	1189.6	865.0	82.8	782.3	.3110	3.21
145.....	355.6	1190.3	863.1	83.1	780.3	.3230	3.20
150.....	358.3	1191.2	861.3	83.0	778.3	.3321	3.01
160.....	363.4	1192.8	857.4	83.5	773.9	.3530	2.83
170.....	368.3	1194.2	853.9	83.7	770.0	.3740	2.68
180.....	373.0	1195.8	850.2	84.0	766.3	.3950	2.54
190.....	377.4	1197.0	847.0	84.1	763.0	.4150	2.41
200.....	381.7	1198.4	843.8	84.3	759.5	.4360	2.30
210.....	385.9	1199.5	840.8	84.5	756.2	.4560	2.20
220.....	389.8	1200.9	837.8	84.8	753.2	.4770	2.10
230.....	393.7	1202.0	835.0	84.8	750.2	.4980	2.01
240.....	397.4	1203.2	832.3	84.9	747.2	.5200	1.93
250.....	401.0	1204.2	829.7	85.0	744.6	.5390	1.85
260.....	404.5	1205.3	827.0	85.2	741.8	.5600	1.78
270.....	407.8	1206.3	824.5	85.3	739.0	.5800	1.72
280.....	411.1	1207.3	822.0	85.4	736.6	.6000	1.67
290.....	414.3	1208.2	819.8	85.4	734.3	.6240	1.61
300.....	417.3	1209.2	817.5	85.4	732.0	.6440	1.55

65 *Discussion of the Steam Tables.* The preceding table shows the various properties of saturated steam and is used in all calculations concerning steam which arise in making tests of the efficiency of a boiler or of an engine. In fact,

it is impossible to make a complete test of an engine without the use of these tables.

66 *Column I* shows the absolute pressure of the steam in pounds per square inch. To find the corresponding gage pressure, 14.7 must be subtracted from the values given in the table.

67 *Column II* gives the temperature corresponding to the pressure at which the water boils and the steam forms.

68 *Column III* represents the total heat in heat units which each pound of steam contains above the freezing point. Particular attention is directed to the fact that steam at high pressure contains very little more heat than steam at low pressure. For example, one pound of steam at 14.7 pounds pressure contains 1146.6 heat units, while steam at 100 pounds pressure contains only 1182.0 heat units, an increase of only 35.4 heat units. This explains why, when steam begins to form, the pressure rises so quickly. Every one who has run an engine knows that after the pressure gets up to 15 or 20 pounds, it takes only a few minutes more to get it up to "the popping off" point. This is due to the fact that only a small additional amount of heat is needed to increase the pressure.

69 *Column IV* shows the latent heat or the heat of vaporization, that is, the heat necessary to change the water into steam after it reaches the boiling point. This quantity becomes smaller as the pressure rises and is about equal to the total heat minus the temperature of the steam above the freezing point.

70 *Column V* represents the quantity of heat which over-

comes the external resistance which the steam overcomes during formation at the given pressure. It also shows how much of the heat may be utilized in an engine taking steam full stroke provided it exhausts into a vacuum and so meets with no resistance at the exhaust.

71 This quantity is always small and does not amount to more than 6 or 7 per cent of the total heat. Incidentally, it proves what has been stated on a previous page; namely, that there is no economy in using steam full stroke in an engine and that there is no particular advantage to be gained, so far as efficiency is concerned, in using high pressure steam. When the steam is used *expansively*, however, there is a great gain.

72 *Column VI*. The heat quantities in this column show the amount of heat needed to change the water from the liquid to the gaseous form. These figures are large and show where the greater part of the heat goes. This heat does no useful work whatsoever, and since the water is in the form of steam when it passes out at the exhaust, it shows that the greater amount of the heat of the steam passes through the engine without doing any work. *This is where the greatest heat loss occurs in the steam engine and it can not be entirely overcome*, although when steam is used *expansively* a considerable amount of the latent heat is turned into useful work. *This is why it is more economical to use steam expansively.*

73 *Column VII* shows the weight of one cubic foot of steam at the different pressures. It will be noticed that the weight increases in direct ratio to the pressures. For in-

stance, at 40 pounds pressure the weight is almost exactly twice what it is at 20 pounds, and at 80 pounds, twice that at 40, very nearly.

74 *Column VIII.* In this column the volume in cubic feet occupied by one pound of water in the form of steam is given. Here again there is an almost exact relation noticed between the pressures and the volumes. At 20 pounds pressure the volume of one pound of steam is 19.91 cubic feet, while at 40 pounds, the volume is only 10.37 cubic feet, thus showing that doubling the pressure halves the volume—very nearly, and proving that Boyle's Law applies reasonably close in the case of steam.

75 *The Use of the Steam Tables.* In order to show something of the utility of the steam tables let us consider the following problem:—

76 *Problem IV.* How many pounds of steam will a 10x12 engine require, running at 250 revolutions per minute, if it takes steam full stroke; steam pressure 100 pounds absolute?

77 *Solution.*

$10 \times 10 \times .7854 = 78.54$ sq. inches, the area of the piston.

$78.54 \times 12 = 942.48$ cu. inches, the volume of steam used per stroke.

$942.48 \times 250 = 235620$ cubic inches per minute.

$235620 \div 1728 = 126.34$ cubic feet per minute.

$126.34 \times 60 = 8180.4$ cubic feet of steam used per hour.

The weight of one cubic foot of steam as given in Column VII of the steam tables is .2270 of a pound, therefore $8180.4 \times .2270 = 1856.95$ pounds of steam used per hour.

78 If steam were cut off at half stroke, only one-half as much steam would be used. If the point of cut off is known it is easy to figure the amount of steam an engine should use in any given time. There are many other practical applications for the steam tables connected with boiler testing, but they are beyond the limits of this lesson.

79 *Theoretical Evaporative Value of Fuel.* One pound of pure carbon contains 14650 heat units. It requires 966 heat units to change one pound of boiling water at atmospheric pressure into steam, consequently, $14600 \div 966 = 15.11$ pounds of water that could, theoretically be evaporated under the above conditions. Practically not more than 12 pounds can be evaporated in a steam boiler under the same conditions. The difference between the theoretical and the practical amount of evaporation is due to losses arising from radiation and the heat lost through the hot gases escaping from the chimney as explained in Lesson V.

80 Ordinary good soft coal contains about the same number of heat units as pure carbon, and consequently will evaporate about the same quantity of water either theoretically or practically.

81 The amount of steam used per hour in various classes of engines is shown in Table IV. The performances of engines are generally expressed in terms of the consumption of water per horse power per hour, because this shows their relative value as power producers.

TABLE IV.

Type of Engine.	Steam Consumption per horse power per hour in pounds.
Plain Slide valve.....	30 to 50
(Non condensing, such as traction engines.)	
Plain Slide valve, condensing.....	25 to 35
Corliss non condensing.....	20 to 30
Corliss condensing	18 to 20
High Speed Triple Expansion condensing.....	11 to 15
Steam Turbine condensing	12 to 25

QUESTIONS FOR PART XIV.

1. Why is a knowledge of heat essential to an engineer?
2. Define heat.
3. Define temperature and show how it differs from quantity of heat.
4. Define absolute temperature and explain how to change Fahrenheit temperature to absolute temperature.
5. Define a heat unit.
6. Define specific heat.
7. Define co-efficient of expansion.
8. What provision is made for taking care of expansion in long runs of steam pipe?
9. How much will a copper telephone wire 1,000 feet long expand if the temperature changes from zero to 100 degrees above?

10. What effect does compressing a gas have on its temperature?
11. Define "the mechanical equivalent of heat."
12. How many foot pounds of work are equivalent to heating 10 pounds of water from zero to 100° Fah.?
13. How hot can water be heated in an open dish?
14. Explain the meaning of the term "latent heat."
15. In what three ways is heat expended in the formation of steam?
16. If an engine takes steam full stroke about what percentage of the total heat can be turned into useful work?
17. Does increasing the pressure of steam increase the efficiency of an engine?
18. Where does the greatest heat loss occur in connection with a steam engine?
19. How may this loss be partially overcome?
20. What information do the steam tables give?

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LESSON WITH QUESTIONS

HORSE POWER, WORK, ETC.

PART XV

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5. Answers **MUST** be written on good white paper, in ink, and only on one side of the sheet.
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School of Traction Engineering

(By Correspondence)

LESSON WITH QUESTIONS

HORSE POWER, WORK, ETC.

PART XV

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

MADISON, WISCONSIN, U. S. A.

LESSON XV.

HORSE POWER WORK, ETC.

- 1 *Introduction.* The unit for measuring the power of a steam engine or of any other prime mover is the horse power. A horse power has already been defined as 33000 foot pounds of work done in one minute. Horse power may be measured either with a steam engine indicator or with a brake. The former is called indicated horse power, often written I. H. P., the latter brake power, written B. H. P.
- 2 *The Indicated Horse Power* of an engine represents the power expended upon the piston by the steam. It represents the power developed in the cylinder, and is somewhat more than what the engine is able to develop at the fly wheel. The difference between the power developed at the fly wheel and that developed in the cylinder, is the amount which is required to overcome the internal resistance or friction of the engine itself. This difference may, and often does, amount to 10 per cent of the power developed in the cylinder.
- 3 *Brake Horse Power.* The brake horse power of an engine represents the power which an engine is able to exert at the fly wheel. It is measured by means of a brake resting on the fly wheel of the engine.
- 4 The *nominal* or rated horse power of an engine may differ from either indicated horse power or brake horse

HORSE POWER, WORK, ETC.

- power and in fact is generally lower than either. It bears no fixed relation to the actual horse power, but is based upon some arbitrary standard adopted by the manufacturer.
- 5 *The Steam Engine Indicator* is the instrument used in measuring indicated horse power. It draws a diagram on a piece of paper which shows the pressures behind the piston at every point in the stroke. From this diagram it is easy to calculate the average pressure on the piston for the whole stroke.
 - 6 If this is known, the power of the engine can readily be worked out by means of the rules already given for calculating work. For example, suppose the average pressure on the piston is 50 pounds per square inch, and suppose the area of the piston is 60 square inches. The total pressure on the piston is therefore: $50 \times 60 = 3000$ pounds.
 - 7 Suppose the piston has a stroke of fifteen inches or $1\frac{1}{4}$ feet. The work done in one stroke of the piston will equal the force exerted upon it, multiplied by the distance it travels in feet, which in this case equals $3000 \times 1\frac{1}{4} = 3750$ foot pounds. If the engine makes 250 revolutions per minute the piston will make $2 \times 250 = 500$ strokes. The total work done will be, therefore, $3750 \times 500 = 1875000$ foot pounds per minute. $1875000 \div 33000 = 56.81$, the indicated horse power.

- 8 The rule for finding the indicated horse power of a steam engine is generally expressed by the following formula:

$$2 \times P \times L \times A \times N = \text{I. H. P.}$$

33000

In which P = the average pressure on the piston in pounds per square inch.

L = the length of the stroke in feet.

A = the area of the piston in square inches.

N = the number of revolutions per minute.

- 9 *Example I.* Find the power of an 8x12 engine running at 300 revolutions per minute, if the average pressure on the piston is 60 pounds per square inch.

- 10 *Solution.* $8 \times 8 \times .7854 = 50.27$ square inches, the area of the piston.

$$2 \times 60 \times 1 \times 50.27 \times 300 = 1809720 \text{ foot pounds of work done per minute.}$$

$$1809720 \div 33000 = 54.83 \text{ horse power.}$$

- 11 *Description of the Indicator.* Fig. 274 is a sectional view of the Crosby indicator, and Fig. 275 shows the same instrument in perspective. The indicator is attached, by means of the thumb nut marked 7, to a pipe tapped into the clearance space at the end of the cylinder. This places the cylinder 5, of the indicator, in communication with the interior of the engine cylinder. Consequently whatever steam pressure exists in one must exist in the other also. The piston 8, is acted upon by the steam from the engine

and compresses the spiral spring above in proportion to the steam pressure exerted upon its lower face. The top of the indicator cylinder is closed by the cap 2, which has an opening through which the piston rod 10, passes. This rod is connected to the lever 16, through link 14. The pencil lever 16, is pivoted at 18, and is connected in such a way that when the piston moves upward, the pencil point

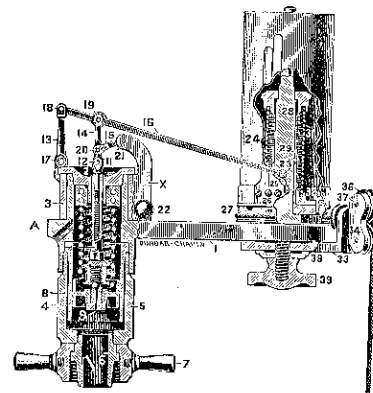


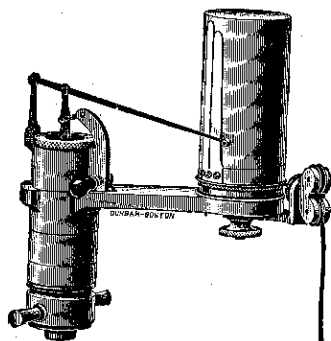
FIG. 274.
Section of Crosby Indicator.

23, moves in a *straight vertical* line. The distance from 12 to 18 is made about 1/5 as long as the distance from 12 to 23, consequently the point 23 will move five times as far as the point 12.

- 12 The arm A carries the drum 24 at its outer end. A cord which is fastened to the cross head is wrapped around a pulley at the lower end of the drum, and causes the latter

to rotate an amount exactly in proportion to the movement of the cross head.

- 13 A spiral spring 31, inside the drum, resists the force of the cross head, and brings the drum back again on the return stroke of the engine.
- 14 The two metal strips, shown just at the left of the pencil point in Fig. 275, are for the purpose of holding a piece of



Crosby Indicator. Fig. 275.

paper, which is wrapped around the drum, and upon which the diagram is to be drawn.

- 15 Posts X and 13 are secured to a collar 3, which fits loosely on the upper end of the indicator cylinder. This collar may be rotated by handle 22, and the pencil be either pressed against the paper or moved away from it.
- 16 *The Indicator Card.* To show how the indicator takes the card, let us suppose the engine piston is at the end of its stroke, and that there is no steam in the cylinder. The

pencil arm and indicator drum are in the position shown in Fig. 275. When steam is admitted to the engine cylinder, it will act with equal force per square inch on both the engine piston and indicator piston. The latter will move up instantly a certain distance, depending upon the pressure of the steam and the strength of the indicator spring. If the pencil point be pressed firmly against the paper on the drum it will draw the vertical line *ab* shown in Fig. 276.

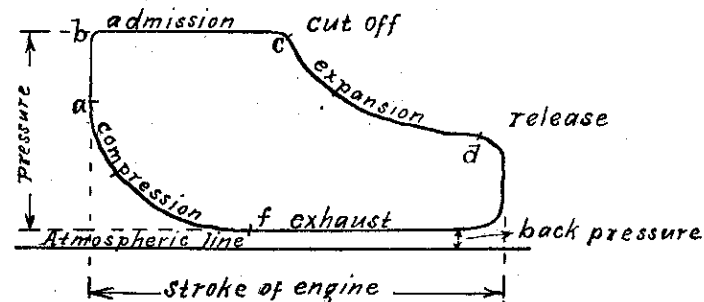
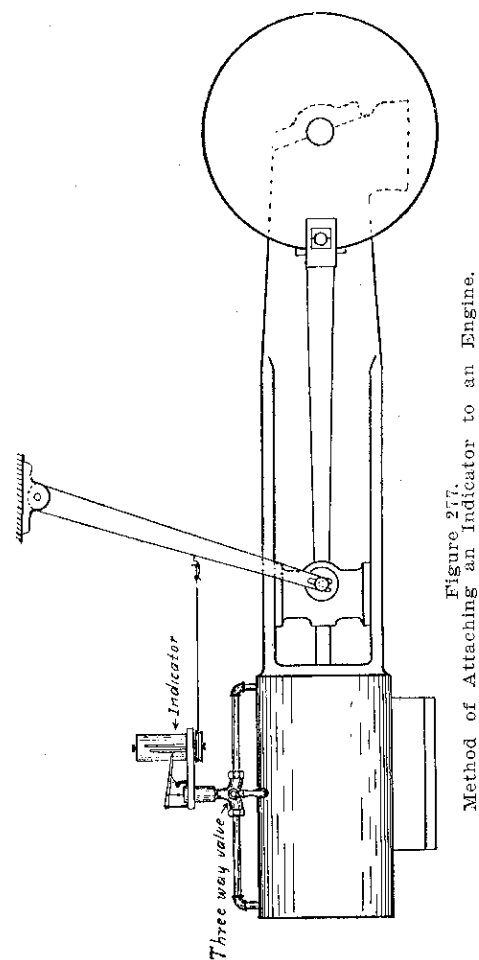


Figure 276.

So long as the pressure in the cylinder remains constant, as it usually does while steam is being admitted, the pencil will remain at the same height on the paper. Consequently the line *bc*, up to the point of cut off, will be a horizontal line. After cut off occurs, the pressure in the cylinder falls, due to the expansion of the steam, and the pencil consequently draws the curved line *cd*. At *d*, the valve opens to the exhaust, and the pressure immediately falls, until at the end of the stroke it is almost nothing. On the



return stroke of the piston the steam is escaping to the exhaust and the pressure is only a little above atmospheric pressure until the point *f* is reached. Here the valve closes the exhaust port and compression begins. The pressure in the cylinder now rises until the end of the stroke is reached, as shown by the line *fa*. At the end of the stroke steam is again admitted, and the pressure immediately jumps to *b*, thus completing the diagram.

- 17 After the card is taken, the valve just below the indicator is closed, shutting steam off from the indicator cylinder;

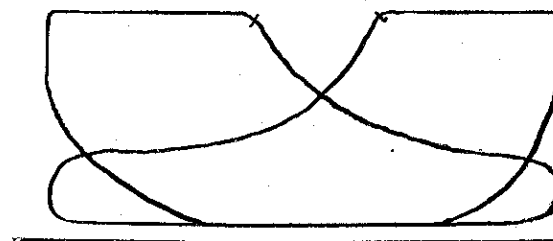


Fig. 278.
An Ideal Indicator Card Showing Diagram From Both Ends of the Cylinder.

then the atmospheric line is drawn, thus completing the card from one end of the cylinder.

If the load on the engine is a constant load, the indicator will go on retracing the same diagram indefinitely. If the load is variable the pressures will also vary, and a number of different diagrams will be drawn.

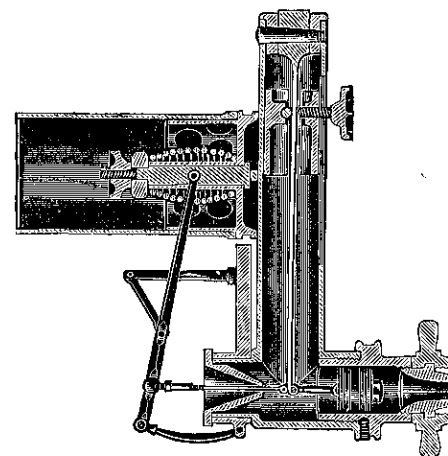
Attaching the Indicator. The usual method of attaching an indicator is shown in Fig. 277. As will be noticed, a

pipe extends from the indicator to each end of the engine cylinder, provided at the point where it connects with the indicator with a three way valve. By turning the valve to the right, the left end of the cylinder is in communication with the indicator, while turning it to the left, puts it in communication with the opposite end, thus enabling the operator to obtain a diagram from each end of the engine cylinder on the same card. Fig. 278 shows the appearance of an ideal card from an engine cutting off at $\frac{1}{3}$ on both strokes.

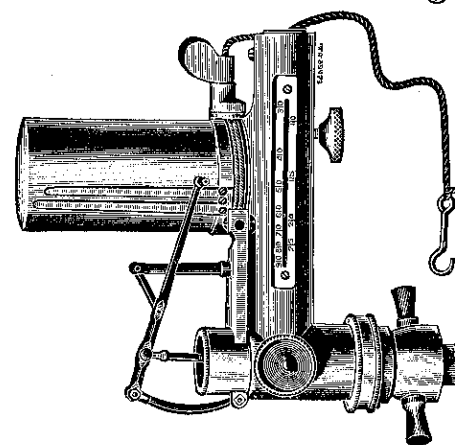
20 Some sort of a reducing motion must be inserted between the cross head and the indicator because the former usually travels farther than the circumferences of the indicator drum.

21 *The Indicator Springs*, that is the springs above the indicator piston, are made of different strengths for different steam pressures, and are designated as 60, 80, and 100 pound springs, etc. A 60 pound spring is one that allows the pencil to move upward one inch for a steam pressure of 60 pounds, and so for the other springs. If the indicator is fitted with a 60 pound spring, and the distance between the atmospheric line and the line *bc* is $1\frac{1}{2}$ inches, it shows that the steam pressure in the engine cylinder is $1\frac{1}{2} \times 60$ or 90 pounds. Knowing the spring used, it is easy to determine the pressures on the piston at any point in the stroke by measuring the diagram.

22 *The Bachelder Indicator* is illustrated in Figs. 279 and 280. It differs from the Crosby indicator in having a T shaped hollow case and an adjustable flat spring. The flat



Section of Bachelder Indicator.



Bachelder Indicator. Fig. 280.

steel spring works in the horizontal body of the case. The outer end of the spring is secured by means of a taper screw and the other is attached to the connecting rod between the pencil lever and the piston.

- 23 The split bushing in the horizontal case is provided with a longitudinal recess for the reception of the spring. This bushing may be moved along the spring and clamped to it at the proper point, as shown by a pointer and scale on the side of the case. The tension on the spring may be ad-

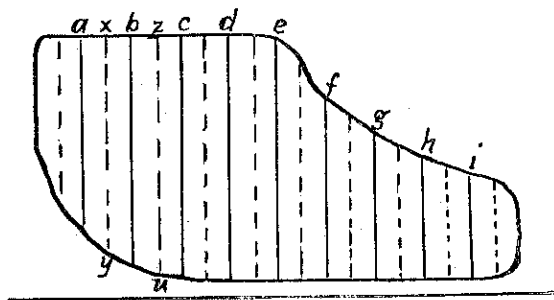


Fig. 281.
Diagram Showing How to Find the Average Pressure Throughout the Stroke.

justed by changing the position of the bushing. All necessary changes of spring can thus be obtained with two flat springs instead of having half a dozen, as is necessary where a spiral spring is used.

- 24 If it is claimed also that since the spring does not work in the same cylinder with the piston, it is not subjected to the high temperatures of the steam and is consequently more reliable.

- 25 *Method of Finding the Average Pressure.* The average or mean pressure on the engine piston may be found in the following manner, by referring to Fig. 281. Divide the diagram into ten equal parts by lines a, b, c, d, etc. Now measure the height of each strip midway between two of these vertical lines, as for example, xy, zu, etc. Add all of these distances together and multiply the sum so found by the spring, and divide the product by 10.

- 26 *For Example,* suppose a 60 pound spring is used, and the sum of all of the distances found by measuring a card is $5\frac{1}{2}$ inches; what is the mean pressure on the piston?

- 27 *Solution.* $5\frac{1}{2} \times 60 \div 10 = 33$, the average pressure in pounds per square inch on the piston. If the area of the piston is 50 square inches, the total average pressure on the piston is $50 \times 33 = 1650$ pounds. In finding the mean effective pressure of the piston, the area of the piston rod must be taken into account on the crank side of the piston. For example, if the piston has an area of 50 square inches, and the end of the piston rod, one square inch, the effective area against which steam acts is 50 square inches on the head end of the cylinder and 49 square inches on the crank side. Consequently, in finding horse power by the indicator, we must use the average pressure on the two sides of the piston for the true average pressure, and the average area of the piston against which steam acts for the true area.

- 28 *To Illustrate.* Suppose the effective area of the piston is 50 sq. inches on one side and 49 on the other, and that the average pressure on one side is 40 pounds, and on the other 44, as determined by measuring the cards. The av-

erage area to be considered is $49 + 50 \div 2 = 49\frac{1}{2}$ square inches, while the average pressure is $44 + 40 \div 2 = 42$ pounds. In using the formula for horse power in this case, $A = 49\frac{1}{2}$, and $P = 42$.

- 29 The average pressure per square inch on the piston, or the mean effective pressure as it is called, is frequently written simply M. E. P. The M. E. P. can be found by means of an instrument called a planimeter, which measures the area of the card very accurately. If this area be divided by the length of the card, the quotient will represent the average height, which, if multiplied by the spring, will give the average pressure in pounds per square inch.
- 30 *The Use of the Indicator.* Indicators are seldom used by the operators of traction engines, and their use is not recommended. In the first place, an indicator is expensive, costing anywhere from fifty to one hundred dollars; in the second place, it requires considerable practice and skill on the part of the operator to obtain reliable results; and in the third place, it is a delicate instrument which is easily damaged if subjected to the rough usage about a traction engine. However, every engineer ought to know something about an indicator, in order to understand what is meant by the term indicated horse power. Furthermore, nearly all of the manufacturers test their engines by taking the indicated horse power and some companies send out the cards with the engines. It is well, therefore, for every traction engineer to be able to read an indicator card.
- 31 *The Things an Indicator Card Reveals.* An indicator card shows not only the horse power of the engine, but to

the experienced eye it reveals what is occurring in the cylinder during every instant of the stroke, together with many points in regard to the design of the engine. Some of the things which may be determined by means of an indicator may be enumerated as follows:

1. The steam pressure on the piston at every point in the stroke.
2. If the valve is set correctly.
3. If the valve leaks.
4. If the valve has the right lead.
5. If the exhaust ports are the right size.
6. If the piston leaks.
7. If the reversing gear is correctly designed.
8. The amount of steam used per horse power per hour.
9. The horse power of the engine.
10. The amount of power needed to overcome the internal friction of the engine.

Besides these there are many more things which may be determined, but the above are enough to show the great usefulness of this instrument in steam engineering generally.

- 32 An indicator is a part of the regular equipment in all well equipped modern stationary steam plants, and cards are taken at regular intervals to determine if the engines are running in the most economical way, and especially to note if the valves are correctly set. An engine may appear to run all right and yet if the valves are not set properly it may waste a large amount of steam, all of which can be detected from an inspection of the indicator card. In

fact, the only *exact* way to set a valve and be perfectly sure of results is to use an indicator.

33 The indicator, by the way, has been invaluable to the designer of engines, and has pointed the way toward the improvements which have so greatly increased the economy of the modern steam engine.

34 *Estimating Horse Power.* The horse power of an engine can easily be found if we know the average pressure on the piston, but this can only be found with an indicator. If the boiler pressure is known, and the point at which cut off occurs, we can, however, estimate the horse power fairly close by using the values given in the table below.

TABLE I.

Point of cut off. *Mean pressure throughout the stroke
with one pound of boiler pressure.*

3/4	.73
2/3	.71
1/2	.62
1/3	.47
1/4	.37
1/5	.30

35 *Explanation of the Table.* If the steam is cut off at $\frac{1}{2}$ stroke, and the boiler pressure is 150 pounds, we must look for the number opposite $\frac{1}{2}$ in the table. This number, .62, multiplied by 150, gives 93 pounds for the average pressure

throughout the stroke. If this quantity be used in the formula $2 \times P \times L \times A \times N$

$\frac{33000}{\text{the result will give us approximately the horse power of the engine.}}$

36 Another rule sometimes given for finding the power of an engine is to use one-half the boiler pressure for the M. E. P.

37 In estimating the horse power of a compound engine, there is no arbitrary rule that we can follow. We must either take an indicator card from both cylinders and figure the horse power of each separately, or else measure the power with a brake.

38 *General Discussion of Indicator Cards.* In order that an indicator card be of any value, the following data should be recorded on the back; namely, the strength of spring, the boiler pressure, the revolutions of the engine, the size of the piston, the length of stroke, the diameter of the piston rod, and the style and make of the engine. The face of the card should show which is the crank end diagram and which the head end. All of these facts are necessary in order to be able to figure the horse power and to judge intelligently the meaning of the lines in case any of them are apparently misplaced.

39 In order to give the student a clearer idea of the meaning of the different lines of an indicator card, a few examples will now be presented.

40 *Admission Too Late.* Fig. 282 shows card presumably taken from a traction engine in which the admission line

slopes to the right instead of standing vertical as it should. This is because the valve has no lead, and consequently the engine piston got well along on its stroke before the ports opened wide enough to admit steam. The corner at *a* is rounded, showing the dragging action of the valve. If the valve had lead, *a* would have been almost a square angle. In the case of a plain slide valve, if it is late at admission,

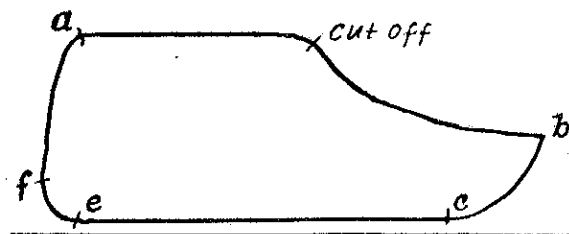


Fig. 282.
Valve Set Without Lead.

that of course makes it late at every other point in the stroke. This causes both cut off and release to occur late. The corner at cut off is always rounded with a plain slide valve because the valve does not close the port instantly.

- 41 It will be noticed that release does not occur until the end of the stroke, and since the steam cannot escape instantly the result is the curved line *b c*, which shows that the piston meets with considerable back pressure during that part of the stroke. When the piston reaches *c*, the pressure has fallen to only a little above that of the atmosphere, at which point it remains until the point *e* is reached. Since the valve has been late all through the stroke, it will

be late at compression, too, as indicated by the point *e* being almost at the end of the stroke. Instead of compression rising to one-half or two-thirds of the admission pressure as it should be, it rises only to the point *f*.

- 42 *Admission Too Early.* Since the valve under discussion is a plain slide valve, it must follow that if it is too late on one stroke, it will be correspondingly early on the other.



Fig. 283.
Valve With Too Much Lead.

Fig. 283 represents the mate to Fig. 282, taken from the other end of the cylinder. Cut off occurs very much earlier and consequently there is more expansion of the steam, making a much smaller card. This shows that the greater part of the work is done on the other stroke. Release occurs long before the end of the stroke, which results in a loss of area, represented between the full and dotted lines at *d*. This shows that the engine loses power and is wasting steam to the exhaust. The loop *a* and the area between the compression and the dotted line *ef* also show loss of power.

- 43 Compression occurs early, as it must when the other

events are early, resulting in a loss of power by doing too much work to overcome the back pressure. Compression in this case is carried higher than the pressure in the steam chest, thus causing the loop at *a*. When the valve opens,

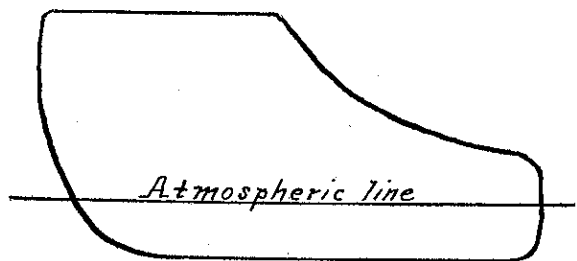


Fig. 284.
Indicator Diagram From a Compound Engine.

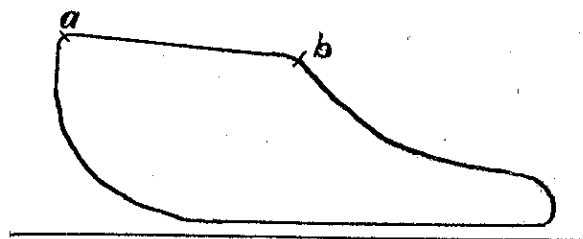


Fig. 285.
Indicator Diagram Showing Wire Drawing.

just before the end of the stroke, to let more steam into the cylinder, steam rushes from the cylinder into the steam chest instead, and the indicator pencil gradually falls until the piston starts on the next stroke under the influence of the pressure in the steam chest.

44 A Card from a Condensing Engine is shown in Fig. 284.

In all non-condensing engines, like traction engines, the atmospheric line is found below the diagram, but in condensing engines, which exhaust into a condenser, the exhaust line will be found below the atmospheric line, a distance proportional to the vacuum in the condenser.

45 Wire Drawing. The sloping line *ab* in Fig. 285 represents what is technically called *wiredrawing*. It shows that

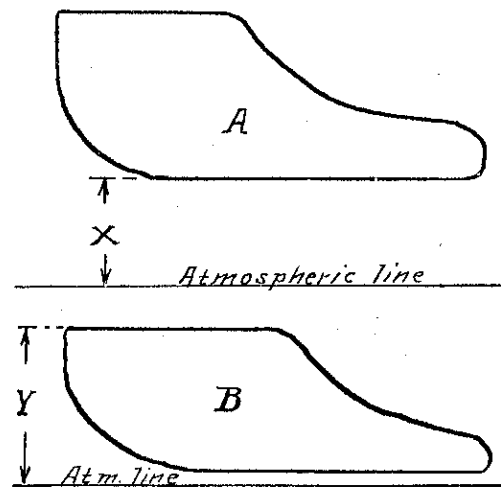


Figure 286.
Indicator Cards From a Compound Engine.

the opening in the steam pipe from the boiler is too small to admit sufficient steam to keep the pressure constant up to the point of cut off. This is generally noticeable in cards taken from a throttle governed engine under a light

load. The governor reduces the size of the opening in the steam pipe, and does not admit enough steam to maintain the pressure in the steam chest.

- 46 The Cards from a Compound Engine are illustrated in Fig. 286. A is from the high pressure cylinder, and B from the low pressure. The atmospheric line under A is at a considerable distance below the exhaust line, showing that the high pressure piston exhausts against a high back pressure. It was pointed out in a previous lesson that the back pressure on the high pressure piston must be about equal to the forward pressure on the low. The pressure

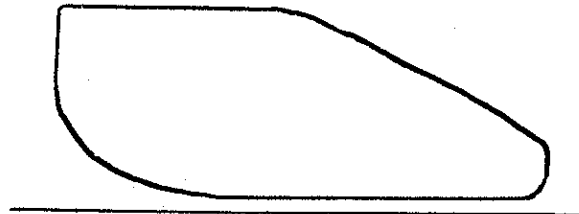


Fig. 287.
Appearance of a Card When the Valve Leaks Steam.

represented by X ought to be about equal to that represented by Y. These two distances are not equal in the figure because the high pressure card must be taken with a much stronger spring than the low pressure card.

- 47 In order to get cards from a compound engine that are worth anything, two indicators should be used, one on each cylinder, and both cards should be taken at the same instant. If a card is taken first from one cylinder, and then a little

later from the other, the card will be useless for figuring horse power because the load on the engine may be different at different times.

- 48 The Effect of a Leaky Valve on the appearance of the indicator card is shown in Fig. 287. Instead of the curve of the expansion line being concave when viewed from above it is convex, showing that steam has entered the cylinder after cut off occurred, and this can happen only when the valve leaks.

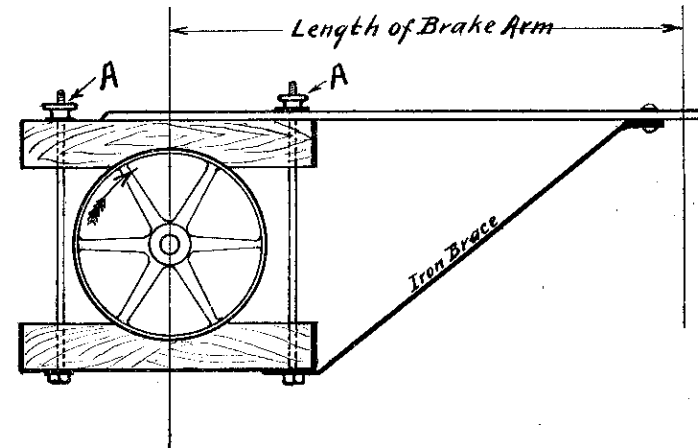


Fig. 288.
A Simple Form of Prony Brake.

BRAKE HORSE POWER.

- 49 A Prony brake is the instrument most commonly used for finding the brake horse power of an engine. A simple form of a brake of this type is shown in Fig. 288. An-

other form is shown in Fig. 289, applied to the fly wheel of a traction engine. Both brakes are very simple in construction and are easy to build. The drawings show them clearly enough without a detailed explanation.

50 *Methods of Finding the B. H. P.* The brake is first set loosely on the band wheel with the brake arm horizontal, and resting on a strut which stands on a platform scales.

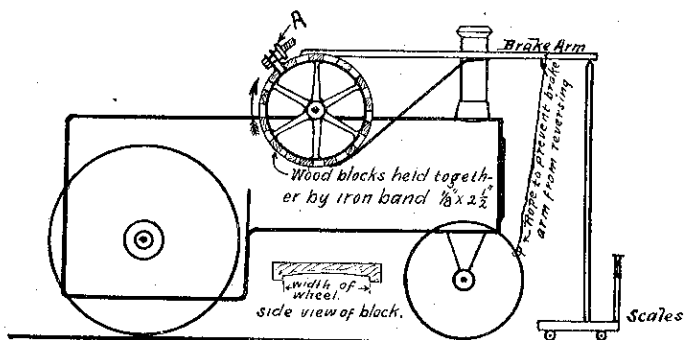


Figure 289.
A. Prony Brake Applied to a Traction Engine.

If the brake is applied to a traction engine, a rope or wire should be fastened near the end of the brake arm and tied to one of the engine wheels. This has nothing to do with finding the horse power, but is simply to prevent accident in case the engine should be reversed. Sometimes the engine will be thoughtlessly reversed in making the test, and if the brake arm is not tied down it will fly around with the wheel with tremendous force and endanger life and prop-

erty. After the brake is adjusted the horse power may be measured in the following manner:

1. Before the brake is tightened on the fly wheel, find out how much weight the brake and strut put upon the scales. This weight is constant and must be subtracted from all of the subsequent readings on the scales because it is not caused by the working of the engine.
2. Oil the brake shoes to prevent them from sticking to the wheel.
3. Bring the engine up to speed slowly, and tighten the adjusting nuts on the brake as much as possible, without slackening the speed of the engine.
4. Pour water on the wheel while making the test to keep the brake shoes from becoming too hot by the friction. A man must keep adjusting the tension on the brake almost constantly too keep the load uniform.
5. Read the weight on the scales every minute during the test and record what appears to be the average reading, rather than either the highest or lowest reading during the minute.
6. Take the speed of the engine with a revolution counter at frequent intervals, or else take the entire number of revolutions during the test and divide by the minutes the test runs.
7. Run the test for ten or twenty minutes, and at the end, find the average weight on the scales (after taking out the constant mentioned in Item 1) which we will

call W , and the average number of revolutions which will be designated N .

- 51 Measure the distance in a horizontal line from the centre of the wheel to the middle of the strut *in feet* and call this distance R .

- 52 The horse power of the engine may now be found by the aid of the following formula; viz.:

$$\frac{2 \times 3.1416 \times W \times N \times R}{33000} = \text{B. H. P.}$$

- 53 *Example I.* Find the horse power of an engine if $W = 120$ pounds, $R = 8$ feet and $N = 250$.

- 54 *Solution.* $2 \times 3.1416 \times 120 \times 250 = 1507968$ foot pounds.
 $1507968 \div 33000 = 45.69$ H. P.

- 55 *Principles Involved in Finding B. H. P.* The friction on the rim of the fly wheel tends to make the brake turn with the wheel. This friction load is resisted by a lever arm pivoted at the center of the wheel and resting on the scales. The force on the scales is caused by the friction at the rim of the wheel acting on an arm whose length is measured from the center of the wheel. The size of the fly wheel need not be considered since the length of the brake arm is taken from the center of the wheel. The same results would be obtained with either a small fly wheel or a large fly wheel on the engine. It would be easy to show how the formula is obtained, but to do so would involve the use of algebra and so it is purposely omitted.

- 56 If the length of the brake arm be made 5 feet $3\frac{1}{8}$ inches,

the horse power may be found as follows: Multiply the average weight on the scales by the average number of revolutions of the engine per minute and divide by 1000—that is, point off three places from the right of the product; the result will be the horse power.

Problems.

1. Find the indicated horse power of an engine having a cylinder 12 inches in diameter, stroke 15 inches and making 260 revolutions per minute.
 2. Find the brake horse power of an engine which makes 250 revolutions per minute; length of brake arm 7 feet 3 inches, average weight on the scales 132 pounds.
 3. The power of a certain engine was taken with a brake having an arm five feet three inches long. The weight on the scales was 288 pounds, and the engine made 300 revolutions per minute; what was its horse power?
 4. Suppose in problem 1 that the speed of the engine were increased to 300 revolutions; how much would it increase the power?
- 57 *The Power of an Engine.* An inspection of the formula:

$$\frac{2 \times P \times L \times A \times N}{33000} = \text{I. H. P.}$$

for indicated horse power, shows that four variable quantities are involved; namely, the average pressure, the length of the stroke, the area of the piston, and the number of revolutions.

- 58 It is perfectly clear that if we should increase any one of these quantities it would increase the power of the engine.
- 59 There are only two of these quantities, however, that the engineer in the field can control; these are the steam pressure and the number of revolutions. If either one or both are increased the engine will have more power.
- 60 *The Efficiency of an Engine* or of any other machine is equal to the work gotten out of it, divided by the work put in. In other words, it equals *output* divided by *input*. In the case of a steam engine the *mechanical efficiency* is equal to the brake horse power divided by the indicated horse power.
- 61 The efficiency of an engine or of any other machine is always less than 100 per cent. This is only another way of saying that no machine can run itself and make its own power. Something must always be allowed for friction in the machine itself.
- 62 The heat efficiency of a steam engine is much lower than the mechanical efficiency. The former ranges from 3 per cent to 25 per cent while the latter often runs as high as 96 per cent. *The heat efficiency* is equal to the heat transformed into useful work, divided by the heat in the coal.
- 63 *Revolution Counters.* There are many forms of revolution counters on the market which automatically record the number of revolutions made by a rotating shaft. One of the simplest of these counters is made the subject of illustration in Fig. 290. It consists of a hardened steel triangular point, shown at the left of the illustration, which en-

- gages by means of a clutch with a worm beneath the dials. The dials are two in number, the outer one graduated from 1 to 100, the inner one from 1 to 49. The numbers of the inner dial are read through an opening in the other one.
- 64 The outer dial has 100 teeth cut on its rim and the inner one has 98. The teeth on both are practically of the same size and both engage with the worm. When the worm makes 100 revolutions the outer dial makes one complete

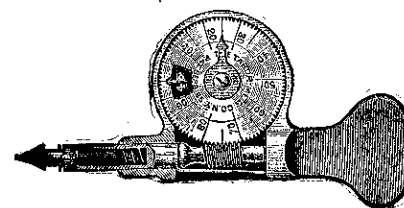


Fig. 290.
Revolution Counter.

- turn and the inner one $102/100$ of a turn. Therefore two teeth, or one division, of the inner disc represents 100 revolutions of the worm. There are, consequently, 49 divisions on the inner dial and the instrument will register 4900 revolutions without being reset.
- 65 *Directions for Using the Counter.* First set the dials to read zero. To do this pull out the spindle until the worm touches the spring, then slip one dial over the other until the notch on the top dial is over the zero of the under dial; then push the spindle back in place and slip the pointer around until it stands over the notch in the upper dial. With watch in one hand, lightly touch the center in the

end of the shaft to be counted with the three-cornered point and then, at the proper instant, as shown by the watch, press it firmly against the shaft and counting will begin and continue until pressure is released. The lower dial counts hundreds and the outer one, as shown by the position of the pointer, counts units. The reading as shown in the figure indicates 4525. The notch on the upper dial rests on 45, indicating 4500, and the pointer shows 25 on the upper dial, thus making 4525.

- 66 *The Value of a Revolution Counter.* The revolution counter is invaluable to a thresherman because it enables him not only to find out the speed of his engine, but the speed of the various shafts in the separator as well. It is impossible to do good threshing unless the cylinder, racks and all other parts run at the correct speed. By figuring the speeds of the various shafts from the sizes of the pulleys, by rules which will appear in Lesson XVI, and then checking these results with the revolution counter, the thresherman can determine if any of the belts are slipping and if so which ones.

QUESTIONS FOR LESSONS XV.

1. What is the difference between indicated horse power and brake horse power?
2. Give a rule for finding indicated horse power.
3. What factor in this rule is determined by the indicator?

4. Draw an indicator card taken presumably from a plain slide valve non-condensing engine cutting off at half stroke.

5. How would you proceed to find the M. E. P. from an indicator card?

6. Why must the area of the piston rod be considered in finding the average pressure?

7. Of what value is an indicator other than finding horse power?

8. Make a sketch of an indicator card taken from an engine in which the valve is set with no lead on one side.

9. What is wiredrawing and how is it indicated by an indicator card?

10. Make a sketch of a Prony brake.

11. Describe how to find the brake horse power of an engine.

12. Find the B. H. P. of an engine if $W = 130$, $R = 7\frac{1}{2}$ feet, and $N = 280$.

13. What is the indicated horse power of an engine if $P = 72$, $L = 15$ inches, $A = 60$ square inches, and $N = 300$.

14. How may the power of an engine be increased by an engineer in the field?

15. Explain how to find the efficiency of any machine.

16. How do you find the mechanical efficiency of a steam engine?

17. Of what value is a revolution counter?

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LESSON WITH QUESTIONS

MECHANICS
PART XVI

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LESSON WITH QUESTIONS

PART XVI
MECHANICS

CLARKE SCHOOL OF TRACTION ENGINEERING

(By Correspondence)

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LESSON XVI.

MECHANICS.

1 *Introduction.* In this lesson in mechanics only a portion of the subject will be discussed; namely, that part relating to simple machines. Indeed, a full course in mechanics involves the use of many of the higher branches of mathematics and presupposes a knowledge of many other subjects not treated in these lessons. All that will be presented of mechanics in this lesson will be a discussion of a few of the simple rules and principles that every good traction engineer should know.

2 *Machines.* A machine is a combination of fixed and movable pieces, which serves to transform power into work. All machines are composed of a combination of two or more elementary devices such as wheels, screws, pulleys, inclined planes, etc. No machine can create power, it simply adapts the power to the work in hand. It is true one can do things with the aid of a machine that he cannot do alone, but the machine adds no power; in fact, it always consumes some power. For example, a man can lift a very heavy weight by means of a jack screw, and at first sight it seems as though the screw adds to the man's power, but as a matter of fact a jack screw is a very inefficient machine because it takes a large proportion, at least half of the power applied, to overcome the friction of the screw. The reason the

MECHANICS.

screw or the lever or any other machine is of so much advantage can best be explained by the principles of work.

3 *Work* has been already defined as the overcoming of resistance through distance, and its amount is measured in foot pounds. Suppose a man has a load of 2000 pounds which he wishes to lift to a height of six feet. The amount of work which must be expended is 2000×6 or 12000 foot pounds. It makes no difference whether the whole 2000 pounds be moved at one time, or whether it be moved piecemeal, there is just the same amount of work to be done. If the man can lift only 100 pounds, he can move the entire weight by dividing it into 20 equal parts and lifting each separately. In doing so he will move the equivalent of 100 pounds a distance of 6×20 or 120 feet. In other words, by dividing the load into 20 parts, he is obliged to travel 20 times as far. He could arrive at exactly the same result by arranging a block and tackle, or a system of levers, whereby he could exert a pull of 100 pounds through a distance of 120 feet, because $100 \times 120 = 12000$ foot pounds of work as before. Whenever one gains an advantage in lifting a weight or moving a load with any mechanical device, he is obliged to move through a much greater distance than the weight moves. Furthermore, the distance in feet the man moves, multiplied by the force he exerts, must equal the resistance the load presents, multiplied by the distance it moves. In practice, the work the man does is a little more than the resistance of the load times the distance it moves, because of the frictional resistances to be overcome in the machine used. We will now

proceed to investigate the laws governing the action of some of the simpler mechanical devices; the first to be considered is the lever.

- 4 Levers are generally divided, for convenience in study-

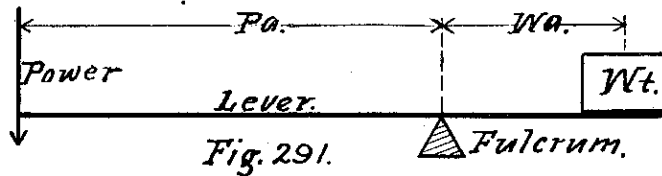


Fig. 291.

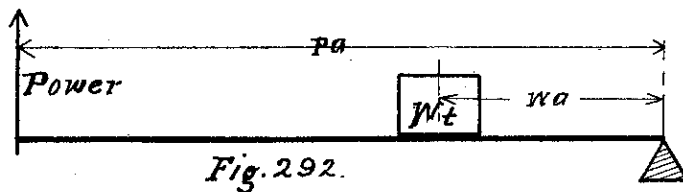


Fig. 292.

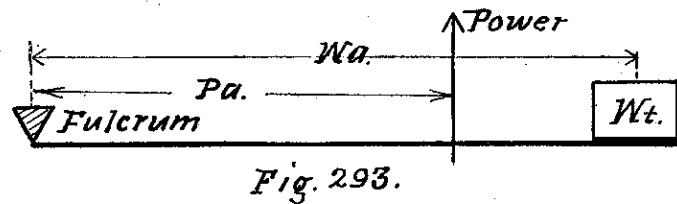


Fig. 293.

The Three Classes of Levers.

ing, into three classes, depending upon where the power is applied, where the weight is located, and where the fulcrum is placed. These different classes of levers are design-

nated as, first class, second class, and third class levers.

- 5 A lever of the *first class* is illustrated in Fig. 291. The power is applied at one end, the weight at the other, and the fulcrum is placed somewhere in between. A crow bar is an illustration of a lever of this kind.
- 6 A lever of the *second class* is made the subject of Fig. 292. Here the fulcrum is placed at one end and power is applied at the other, the weight being placed in between. A practical illustration of a lever of this kind is a wheel barrow. The wheel axle takes the place of the fulcrum, the power is applied at the ends of the handles, and the weight is placed in the box between the power and the fulcrum.
- 7 A *third class lever* is shown in Fig. 293. In this case the fulcrum is placed at one end of the lever, the weight at the other, and the power is placed at some point between. A bundle of grain lifted on the point of a pitchfork is a familiar example of a lever of this class. In Figs. 291 and 292 the weight moved is considerably greater than the power applied, but in the third class lever the number of pounds of power used must be greater than the weight. The advantage in this case lies in the ability to move the weight through a much greater distance than the power moves, while with levers of the first and second class the power moves much farther than the weight. In every case, however, the following law will be found to apply.
- 8 *Law I.* The weight, multiplied by the distance it moves, equals the power multiplied by the distance it moves. The

truth of this law is illustrated in Fig. 294. The lever is six feet long and the fulcrum is placed two feet from the end. If the weight weighs 600 pounds and moves one foot, there will be 600 foot pounds of work done. It will be found on measuring that the distance a , passed through by the power is twice the distance b , therefore the power has moved two feet. Consequently the power will equal one-half of the weight, or 300 pounds. We then have 300, the power, times 2, the distance it moves, equals 600 foot pounds; also 600, the weight, times 1, the distance the

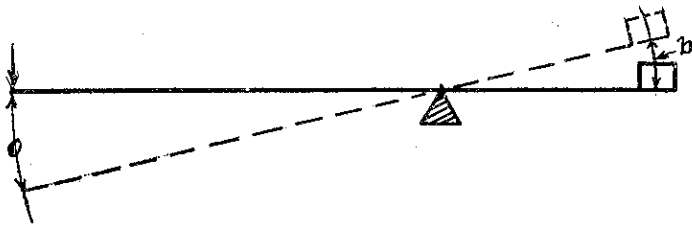


Figure 294.

weight moves, equals 600 foot pounds, thus proving the law.

- 9 *The Rules of Levers.* The distance from the power to the fulcrum is called the power arm, and the distance from the weight to the fulcrum is called the weight arm. These distances are designated in Figs. 291, 292 and 293 as wa for weight arm, and pa for power arm.
- 10 *Rule I.* The power multiplied by the power arm is equal to the weight multiplied by the weight arm. There are thus four quantities involved in all problems in levers. If

three are known, the fourth can readily be found, as will be shown by the following examples.

- 11 *Example 1.* In a certain first class lever the power arm is 12 feet long, the weight arm $1\frac{1}{2}$ feet long, and the weight is 2000 pounds; how much power must be applied to move the weight?
- 12 *Solution.* The weight, 2,000, times the weight arm, $1\frac{1}{2}$, equals 3000. The power is not known, but from the rule we know that if it be multiplied by the power arm, the product will be 3000. Therefore, $3000 \div 12 = 250$ pounds, the power.
- 13 *Example 2.* If the weight arm is 4 feet long and the power arm 6, how large a weight can be lifted with a power of 150 pounds?
- Solution.* $6 \times 150 = 900$, the product of the power and the power arm.
 $900 \div 4 = 225$ pounds, Ans.
- 14 *Example 3.* If the weight is 100 pounds in a third class lever, the weight arm 4 feet, and the power 160 pounds, how long must the power arm be?
- Solution.* $100 \times 4 = 400$, the product of the weight and the weight arm.
 $400 \div 160 = 2\frac{1}{2}$ feet, the length of the power arm.
- 15 *Compound Levers.* Where two or more levers are arranged in such a way that the power for the first lever becomes the weight for the second, we have what is known as a compound lever, an example of one style of which is given in Fig. 295. An arrangement of this kind makes it

possible to lift an enormous weight a slight distance with only a small amount of power as shown in the following example:

16. *Example 4.* How much power must be applied at P' , in Fig. 295, to lift a weight of 20000 pounds, using the same dimensions of levers as shown in the figure?
17. *Solution.* Beginning with the right hand lever we find that the power arm is 75 inches long and the weight arm

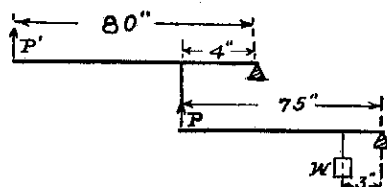


Fig. 295.
A Compound Lever.

three; consequently, the unknown power P , $\times 75 = 3 \times 20000$, or 60000. Therefore, $P = 60000 \div 75 = 800$ pounds. The power for the first lever is the weight for the second; consequently, if we work out the power needed for the second lever to lift a weight of 600 pounds, the problem will be solved.

18. Applying Rule 1 of levers we have $80 \times P = 4 \times 800$, or $80 \times P = 3200$. In other words, the unknown power P' times 80 = 3200. Consequently P' must be equal $3200 \div 80 = 40$ pounds, Ans.

19. Steelyards and balances for weighing are examples of the practical application of simple levers, while platform scales are an example of the most common use that is made of compound levers.

20. *Pulleys* are made use of a great deal in various kinds of engineering work, and a knowledge of how to hitch them up to obtain the greatest possible advantage is desirable.

21. A *Single Fixed Pulley* is represented in Fig. 296. In this case the power applied at P just equals the weight,

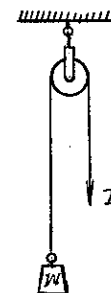


Fig. 296.
A Single Fixed Pulley.

that is, if we assume that both the rope and pulley are without friction. The truth of this may be proven by Law 1, because it will be noticed that the power and weight both move through equal distances. The only advantage

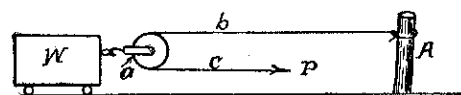


Fig. 297.
A Single Movable Pulley.

in using such an arrangement is to change the direction taken by the source of power. A well bucket is a well-known example of the use of a pulley arranged in this way.

22 A *Single Movable Pulley* is shown in Fig. 297. Here the pulley is attached to the weight, and one end of the rope is fastened to the post A. If the distance from the weight to the post is ten feet, the point *a* of the rope will be found just ten feet on the opposite side of the post when the weight reaches the post. Thus it will be seen that the power must move just twice as far as the weight. Consequently, if a pull of 100 pounds is required to move the weight without a pulley, a pull of 50 pounds will move it with the arrangement just described. The truth of this statement may be proved by again referring to Rule I.

23 The work to be done is equal to $100 \times 10 = 1000$ foot pounds, but if the power moves twenty feet instead of ten, it can be reduced from 100 pounds to 50 pounds, because $50 \times 20 = 1000$ foot pounds as before. The general principles of work and energy are seen to apply in this case just as in the other machines already discussed. There is, however, a specific rule governing all cases of pulleys which is easier to apply than the general *Law*, which may be expressed as follows:

24 *Rule II.* The load, divided by the number of ropes *pulling* it, equals the *power* required. In Fig. 297 above, the load is divided equally between *b* and *c*.

25 In Fig. 298 no advantage is gained by adding the pulley B, except to change the direction of the power. While there are three ropes between the weight and the post, it will be noticed that only two are attached to the weight, and so the power will equal only half what would be required to move the weight without pulleys.

26 Another example of a single movable pulley in connection with one fixed pulley is illustrated in Fig. 299. The rope is fastened to the weight, then passed through a pulley

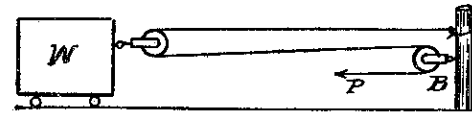


Fig. 298.
One Fixed and One Movable Pulley.

fastened to the post, and then threaded through a pulley attached to the weight. An inspection of the figure reveals the fact that the weight, and consequently the power needed, will equal one-third of the load.

27 *Block and Tackle* is the term applied to a couple of pulley

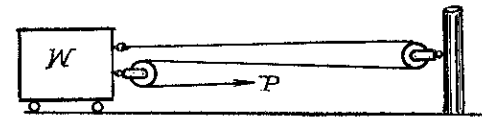


Fig. 299.

blocks each containing two or more pulleys, together with the necessary ropes. An example of a device of this kind appears in Fig. 300. Six ropes leave the weight, and consequently the power equals one-sixth of the load. Of



Fig. 300.
Block and Tackle.

course in actual practice a little more power would be necessary in order to overcome the friction of the ropes and pulleys. In the case of large ropes, the power required to bend them around small sized pulleys is sometimes of considerable magnitude.

- 28 A *Differential Pulley* is shown in Fig. 301. It consists of two drums of different size, one large, the other small. The rope to which the weight is attached is wound up on

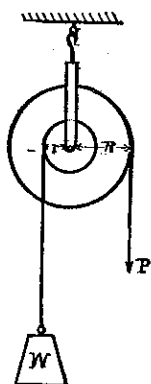


Fig. 301.
A Differential Pulley.

the smaller drum, while the rope to which the source of power is attached unwinds from the large one. The advantage gained is due to the difference in size between the drums, and may be explained by the rule of levers rather than by the rule of pulleys. The fulcrum is at the center of the drums, the power arm is equal to the radius of the

large drum, and the weight arm to the radius of the small drum. If R is 12 inches, and r 6 inches, the power will equal one-half of the weight. A windlass acts in just the same way as a pulley of this kind, the radius of the drum being the weight arm and the length of the arms measured from the center of the drum, the power arm.

- 29 A *Compound Pulley* is sometimes used, see Fig. 302. In this case the ropes a b c d e and f , each support an equal

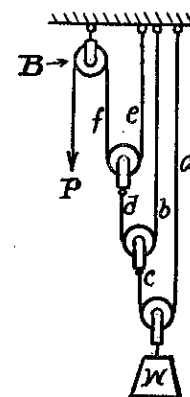
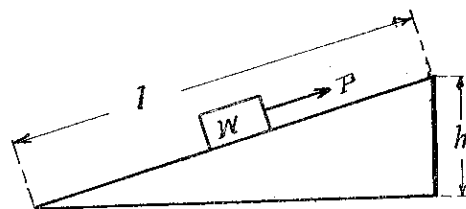


Fig. 302.
Compound Pulleys.

share of the weight, and so the power P equals one-sixth of the weight. The pulley B simply serves to change the direction of the motive force P .

- 30 *The Inclined Plane.* A man can roll or drag a heavy weight up an incline when he would find it impossible to lift the whole weight through the same vertical distance. This

may also be explained by Law 1. For example, if the weight is to be lifted five feet vertically, and is pushed up an incline ten feet long, it is clear that, barring friction, it will only require a push equal to half of the weight, because the distance passed over by the weight is just twice as great as if it were lifted straight up. The rule governing



The Inclined Plane. Fig. 303.

all problems of the inclined plane is as follows: (See Fig. 303.)

31. *Rule III.* The force required equals the weight, multiplied by the height of the incline h , and this product divided by the length of the incline l .

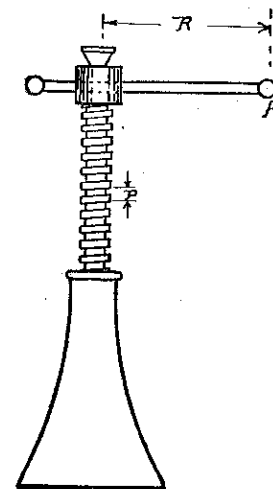
32. *Example 5.* How much force will be required to roll a barrel of salt weighing 200 pounds up an inclined plank 12 feet long, if the upper end of the plank is three feet from the floor?

33. *Solution.* $200 \times 3 = 600$, the weight times the height.
 $600 \div 12 = 50$, the number of pounds of force needed.

34. *The Screw.* A screw has a right hand thread if, when facing the end upon which the screw is cut, the nut must be

turned to the right to be turned on, and left handed if the nut turns on in the opposite direction.

35. The pitch of a screw is the distance from the edge or point of one thread to the same point of the next one. A six pitch screw has six threads per inch of length and so for other pitches. The rule governing the screw when used

Fig. 304.
Jack Screw.

as a mechanical power, as in the case of a jack screw, is as follows:

36. *Rule IV.* The force required to operate the screw is equal to the product of the weight and the pitch, divided by the circumference of the circle through which the force

moves; or, the weight which can be lifted by a known force is equal to the product of the force by the circumference of the circle through which it turns, divided by the pitch.

- 37 *Example 6.* If R, in Fig. 304, is 18 inches, P is $\frac{1}{4}$ of an inch, and the force exerted at A is 200 pounds; how much weight can be lifted?

- 38 *Solution.* $2 \times 18 \times 3.1416 = 113.1$, the circumference of the circle through which the force moves.
 $113.1 \times 200 = 22620$, the force times the circumference.

$$22620 \div \frac{1}{4} = 22620 \times 4 = 90480 \text{ pounds, Ans.}$$

- 39 The principle of work and energy of Law 1 also applies to the problem of the screw, and is involved in the rule given above. The weight multiplied by the vertical distance it moves, must equal the power multiplied by the distance it moves in going around the circle.

BELTING.

- 40 The subject of belting is one that the traction engineer ought to give careful consideration. He ought to study the different kinds of belts, and give particular attention to their proper care and treatment. By so doing he will save money in belt repairs, save time, and keep his machinery in better running order.

- 41 There are three classes of belting used generally by threshermen, leather, rubber and canvas. The first to be discussed will be leather belting, followed in order by the other two.

- 42 *Leather Belting* is made in various grades, and sold for various prices, depending supposedly upon the quality.

The quality of a leather belt depends upon the kind of hide used, the method of tanning and the part of the hide the

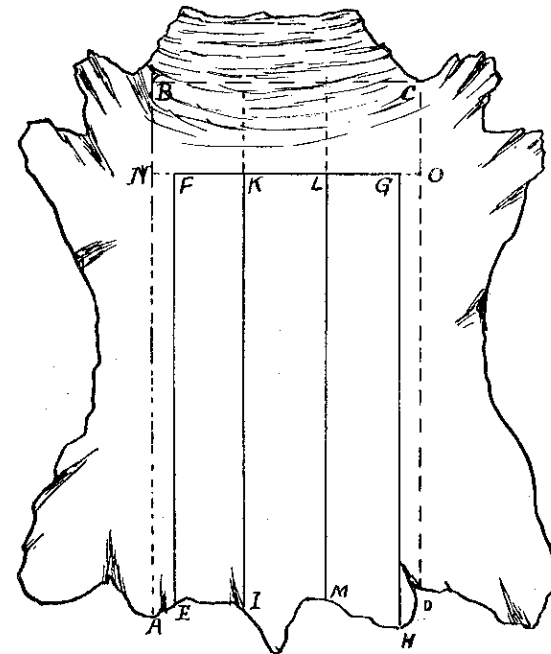


Figure 305.

leather is cut from, together with the care used in manufacturing the belt.

- 43 That portion of the hide within the lines ABCD in Fig. 305 is what is used in making leather belts and is called a "butt." The portion of the hide outside of the butt is

from the belly of the animal; it is soft and flabby, has little elasticity and is unfit for belt stock. The better grade of belting is cut from the portion EFGH, while the very best strictly *short lap* belting is cut from the center of the hide and is bounded by the lines IKLM. The shoulder and neck stock NBCO is used for an inferior grade of belting. It is thick and heavy and varies greatly in elasticity. It has a tendency, when made up into belts, to stretch unevenly.

- 44 Since all strips except those cut from the center of the hide will stretch more on one edge than the other, it is customary to take out most of the stretch before the belt is put into use. Belting that has *all* the stretch taken out is called *dead* belting. It is not considered first class because it will not give under sudden heavy loads like live belting, and so puts more strain on the machinery.
- 45 Other things being equal, a heavy belt is more desirable than a light one. It is cut from a better hide and is stronger than a light belt. When belts are required heavier than can be cut from a single thickness of hide, it is necessary to glue two or more thicknesses together, making double or triple belting. A good grade of fish glue is used for this purpose without the use of rivets to hold the strips together, in the better grades of belting.
- 46 Where a single belt can be used to perform the work, it is more satisfactory than a double belt. Where the power transmitted would require single belts of considerable width double belts may be used, but they should not be made to

pass over pulleys of small diameter, as the continual bending will cause them to crack at the glued joints.

- 47 *Which Side of Belts to Run Next to the Pulley.* The strongest section in a piece of belting, and the part that is most elastic, is on the flesh side. The hair or smooth side is comparatively weak, brittle and liable to crack. For these reasons the hair side should be run next to the pulley because it brings the stronger flesh side, whose fibres can best resist tension, on the outside where the strain is greatest; while at the same time the less elastic hair side is close to the pulley where it is under compression. Belts run in this way very seldom crack, while if run with the flesh side next to the pulley, fine cracks crosswise of the belt soon appear, which grow deeper with use and finally ruin the belt. The hair side of the belt, being smoother, makes better contact with the pulley. There is more surface in contact and consequently the friction is better. Tests show that a belt run in this way will actually transmit 25% more power, other conditions of course being equal, than if the flesh side is run next to the pulley.
- 48 *The Strength of Leather Belting.* The tensile strength of leather belting is somewhat variable, running between 2000 and 5000 pounds per square inch, that is, a piece of belting $\frac{1}{4}$ of an inch thick and 4 inches wide will stand the above strain before breaking. The strength of a properly laced joint is somewhat less, ranging from 1000 to 2000 pounds.
- 49 *The Power Which a Leather Belt Will Transmit* varies according to conditions. It depends upon its thickness,

linear velocity and width as shown by the following principles.

1. Doubling the thickness of a belt multiplies its power by 1.7, the width and velocity remaining the same.
2. Doubling the width of a belt doubles its power, the thickness and velocity remaining constant.
3. Doubling the velocity of a belt doubles its power, the width and thickness remaining constant.

50 The following table shows the H. P. belting will transmit with safety. In these calculations it is assumed that the belts run about horizontally, the arcs of contact being about one-half of the circumference of the smaller pulley. If this arc is materially reduced it will make a proportional reduction in the H. P. which the belt is able to transmit.

TABLE I.

Horse Power a Belt Will Transmit with a Velocity of 100 Feet per Minute.

Width in Inches.	Single Belting.	Double Belting.
1	.09	.153
2	.18	.306
3	.27	.459
4	.36	.612
5	.45	.765
6	.55	.935
7	.64	1.008
8	.73	1.241
9	.82	1.394
10	.91	1.547
11	1.00	1.70
12	1.09	1.76
14	1.27	2.159
16	1.45	2.465
18	1.64	2.788
20	1.82	3.094
22	2.00	3.40
24	2.18	3.706

51 *Explanation of the Table.* The above table is made out on the basis that a single leather belt one inch wide, traveling about 1100 feet per minute, will transmit one horse power, while a double leather belt of the same width, traveling at the same speed, will transmit 1.7 horse power. The use of the table can be most easily explained by an example.

52 *Example 7.* A belt six inches wide passes over a 30-inch pulley making 300 revolutions per minute; how many horse power will it transmit?

53 *Solution.* The velocity of the belt will be equal to the velocity of a point on the rim of the pulley. Every time the pulley makes a revolution, the belt moves a distance equal to its circumference. If we find the circumference of the pulley and multiply by the number of revolutions it makes in one minute, we will find the velocity of the belt.

$2 \times 3.1416 = 6.2832$ feet, the circumference of the pulley.

$6.2832 \times 300 = 1884.96$ feet per minute, the velocity of the belt.

A six-inch belt traveling 100 feet per minute will, according to the table, transmit .55 of a H. P. If it travels at 1884 feet per minute, it will transmit $18.84 \times .55 = 10.36$ H. P. or practically ten horse power.

54 There are other rules and tables for calculating the power of belting in common use, but the one given above gives good safe results.

55 *Another Rule for Belting.* A single leather belt traveling at a speed of 900 feet per minute will transmit one horse power per inch of width, when the arc of contact is not less than 180 degrees on the smaller pulley. Consequently to find the horse power a belt will transmit, proceed as follows:

Rule V. Multiply the velocity of the belt in feet per minute by its width in inches and divide by 900.

56 This rule gives somewhat larger results than the table and is not quite as safe, although in actual practice belts

are often given a much heavier load than called for by either rule.

57 *Fastening the Ends of Belts.* The two ends of a belt may be joined together by lacing, by metallic fasteners, or by gluing. For belts provided with a tightener pulley, gluing is the most satisfactory for the reason that it is stronger than either of the other fastenings, and leaves the joint just as smooth as the rest of the belt. In the case of a swift running belt, or one running over small pulleys, the glued joint is much better because where a laced joint or one put together with fasteners is used, it does not hug the pulley so close when the joint passes over, and slipping is almost sure to occur. On account of the stretching of a new belt a glued joint cannot be depended upon unless a tightener of some sort is provided.

58 There are a large number of different styles of metallic fasteners on the market, some of which are very satisfactory. They possess the great advantage of being easily and quickly put in place when the belt breaks or needs relacing. Unless fasteners of the right sort are used they are apt to tear the leather much more than leather lacing.

59 *Lacing Belts.* The principal fastening used by threshermen is rawhide lacing, and when properly put in it is very satisfactory. The belts should be examined every time the machinery stops and if a strand is broken the lacing should be repaired at once. The old adage of "a stitch in time saves nine" applies just as surely to belting as it does to clothing.

60 There are a good many different ways to lace a belt, but

for all ordinary purposes the lacings herewith described and illustrated will be found sufficient. Fig. 306 represents a style of lacing used on belts from 3 to 4 inches wide. The side marked P is the pulley side, and the other is the outside. In all lacing the laces should run parallel with the

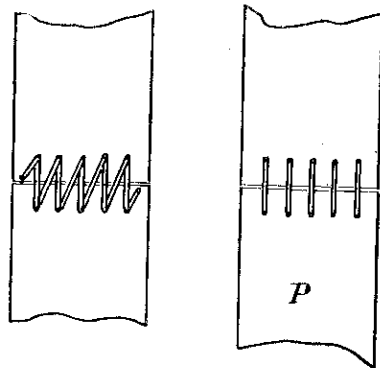


Figure 306.
Single Lacing for Narrow Belts.

belt on the pulley side. Where the laces cross on the side next to the pulley they are very liable to wear and cut at the crossings.

- 61 Many people seem to think that the heavier a lacing is, the more durable it is, but such is not necessarily the case. A thick heavy lacing strains itself in going around the pulleys, and in a short time it has either worn out or has torn the leather out between the holes. The lacing should be as near as possible like the rest of the belt so that it will pass over the pulleys without shock or jar. After a new

lacing is put in it should be laid on a block and hammered to flatten the laces and smooth the joint as much as possible.

- 62 *General Directions for Lacing.* Be careful to cut the ends of the belt perfectly square. Do not depend upon the eye to square the belt, but use a square. Punch the holes so that they will come exactly opposite each other when the two ends of the belt are brought together. Use an oval punch

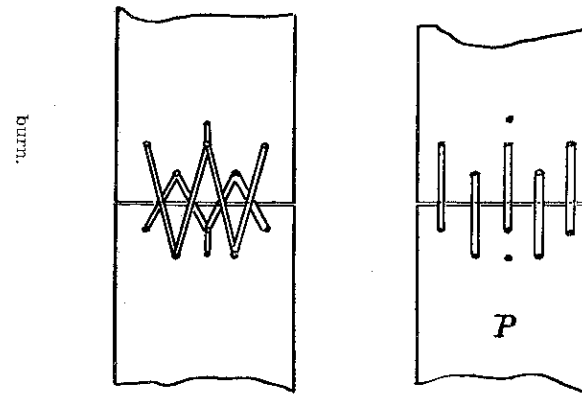


Figure 307.
Double Lacing for Medium Belts not too Heavily Loaded.

and punch the holes so that the long diameter of the holes is parallel with the belt. An oval punch cuts out less of the width of the belt than a round one.

- 63 The edges of the holes should not be nearer than $\frac{3}{4}$ of an inch to the sides of the belt nor nearer than $\frac{7}{8}$ of an inch to the ends of the belt in belts six inches wide and over. For single belts three inches wide or less, $\frac{1}{4}$ -inch lacing

is sufficient. For belts from 6 to 8 inches wide, $\frac{1}{2}$ -inch lacing is wide enough. Heavier belts require wider lacing in proportion to the width and thickness of the belt. Lacing $\frac{3}{4}$ of an inch wide is, however, wide enough for the heaviest belts. The belts that a thresherman has to do with do not require lacing heavier than $\frac{1}{2}$ inch wide.

64 Fig. 307 shows a style of lacing adapted for belts 6 to 8 inches wide. In all cases the lacing starts in the middle

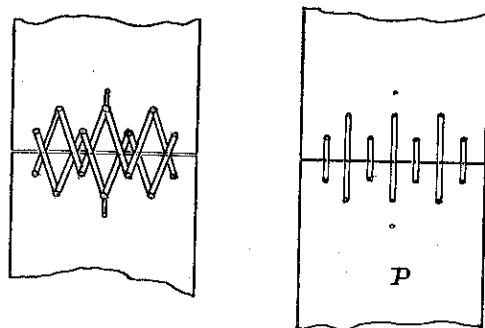
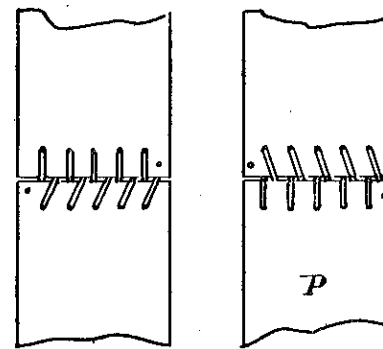


Figure 308.
Double Lacing for Medium-Sized Belts.

hole, both ends being put through from the pulley side. One end is laced out to one side and then back to the middle, and the other end of the lace is laced to the opposite side and back. The ends of the lace do not need to be tied together or knotted, as the friction of the lacing in the belt is sufficient to hold the ends in place. Fig. 308 shows still another style of lacing that is in common use, while Fig. 309 shows a style of hinge lacing used on belts that are

required to pass over a small pulley smoothly, such as a governor belt or the feeder belt which has to make short, sharp turns.

65 *The Care of Leather Belts.* A leather belt should be kept clean and free from grease. It should not be allowed to get wet, because when it gets wet it shrinks and becomes hard



Single Hinge Lacing.

Fig. 309.

and brittle. All leather belts should be put under cover at night to keep them dry, or when a rain storm comes on. All leather belts should be given a coat of neatsfoot oil at the beginning of each season's run, or better yet at the end of the run after they have been thoroughly cleaned, and before they are stored away for the winter. Neatsfoot oil will keep a belt soft and pliable and in the best possible condition for work. There is no belt dressing that the writer is ac-

quainted with better than neatsfoot oil, though there are no doubt some that are just as good. The principal thing in leather belting is to keep it soft and pliable so that it will not crack, and so that it will cling tightly to the pulley. Mineral oil will rot a belt and make it soggy and inelastic. It should never be used.

- 66 *Rubber Belting* is made of canvas and then coated with a rubber compound. It is not affected very much by damp weather and is very satisfactory for outdoor use, especially for the main drive belt. The seam should always be on the outside and not next to the pulleys. Care should be taken with rubber belts that the edges do not get frayed by rubbing against some rough surface. A bar of hard soap, such as laundry soap, applied to the pulley side of a rubber belt will cause it to grip the pulleys tighter and is about as good as anything that can be used. A sticky substance should not be used for a belt dressing on rubber because it will cause the rubber to peel off when the belt runs over the pulleys. Oil should not be used on a rubber belt because it rots the rubber. The following dressing has been recommended for rubber belting that is slightly worn: "Equal parts of black lead and litharge mixed with boiled linseed oil to which add enough japan to make it dry quickly." Apply the dressing with a brush.

- 67 *Canvas Belting* is used a great deal for drive belts. It is made of a good grade of cotton and is tightly woven, after which it is sewn together and then thoroughly impregnated with a special kind of paint which fills the fibres and prevents moisture from acting upon the cotton. Canvas belt-

ing is often referred to as Gandy belting, but this is wrong. The Gandy Mfg. Co. were the first to make canvas belting, but at the present time there are a number of companies doing the same kind of business. The term Gandy belting does not apply to all canvas belts.

- 68 *Belt Pulleys* are made either of wood, pressed steel or cast iron. Most of those used about a threshing machine

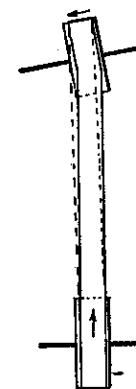


Figure 310.

are made of cast iron. The faces of pulleys upon which the belt runs are usually made *crowning*, that is, slightly higher in the center than at the edges. A pulley so made holds a belt better than one that is flat, for the reason that when pulleys are *parallel* the belt runs to the highest point. If this highest point is in the middle of the pulley both edges run toward the center and so the belt runs true. If the pulleys are not parallel, the belt will run to the low

side because it changes direction at the point where it runs on the pulley that is out of line, as shown in Fig. 310.

69 In order to remove a belt from a running pulley press against the edge of the belt that is *running on* the pulley. Pressing against the side that is running off does not influence the direction of the belt.

70 Whenever possible, the lower side of a belt should be

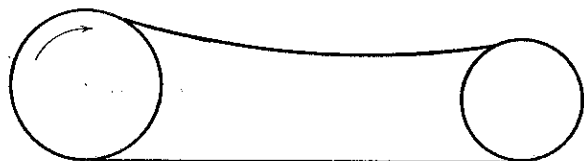


Fig. 311.

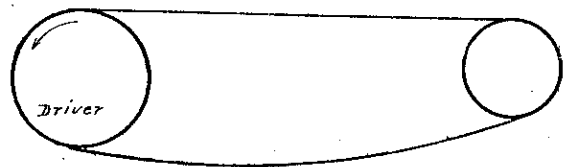


Fig. 312.

the tight or driving side as shown in Fig. 311. When the top side of the pulley is the driving side, the lower side of the belt hangs down as in Fig. 312. The arc of contact of the belt is thus considerably reduced and the belt will not transmit so much power.

71 Fig. 313 shows how a belt may be made to drive from one shaft to another at right angles to the first. The necessary condition for driving in this way is that the center

of the face of pulley A be in the same plane as the center line of pulley B. In other words, the pulley B must be so placed that a line drawn parallel to and midway between its two edges, such as the line *c d* in the figure will just touch the middle of the face of pulley A.

72 The curved side of the belt is the slack side. Machinery driven in this way cannot be reversed because the belt will

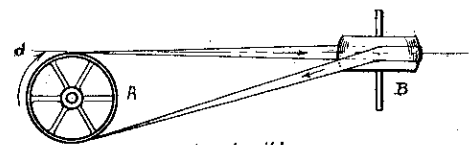


Fig. 313.
A Quarter Twist Belt.

then run off the pulleys. Pulley B should be about twice as wide as the belt.

73 *Rules for Calculating the Speed of Pulleys.* In figuring the speed of pulleys their circumferences need not be considered. All that is necessary to know is their diameter, because the circumferences are proportional to the diameters.

74 *Rule VI.* Given, the diameter of the driver and its number of revolutions per minute, and the diameter of the follower; to find the speed of the follower pulley: Multiply the number of revolutions of the driver by its diameter, and divide the product by the diameter of the follower; the quotient will be the speed of the follower.

75 *Example 8.* The diameter of the driving pulley is 42

inches, number of revolutions 240, diameter of the follower pulley 10 inches; find the speed of the follower.

76 *Solution.* $42 \times 240 = 10080$.

$10080 \div 10 = 1008$, Ans.

77 *Rule VII.* Given, the number of revolutions and diameter of the driver, the number of revolutions of the follower; to find the diameter of the follower: Multiply the diameter of the driver by the number of revolutions of the driver, and divide the product by the speed of the follower; the quotient will give the diameter of the follower.

78 *Example 9.* The diameter of the driving pulley is 40 inches, and its number of revolutions 250 per minute; what must be the diameter of the follower if it runs at 360 revolutions per minute?

79 *Solution.* $40 \times 250 = 10000$.

$10000 \div 360 = 27.7$, Ans.

Since pulleys are not made in odd fractions of an inch we would select the nearest size smaller, $27\frac{1}{2}$ inches, as the proper diameter of pulley to use. This would make the driver run a little too fast, but since there is always some belt slippage it would very likely give nearer the correct results than a pulley of the exact size figured.

80 *Rule VIII.* Given, the diameter and number of revolutions of the follower, and the diameter of the driver; to find the number of revolutions of the driver: Multiply the diameter of the follower by its number of revolutions and divide the product by the diameter of the driver; the quotient will be the speed of the driver.

81 *Example 10.* The diameter of the driving pulley is 36

inches. Number of revolutions of the driver, 240. Diameter of the follower, 12 inches. How many revolutions does the follower make?

82 *Solution.* $240 \times 36 = 8640$

$8640 \div 12 = 720$. Ans.

83 *Rule IX.* Given, the speed of the driver, the speed of the follower, and the diameter of the follower; to find the diameter of the driver: Multiply the diameter of the follower by the number of revolutions it makes per minute, and divide the product by the number of revolutions made by the driver; the quotient will be the diameter of the driver.

84 *Example 11.* The speed of the driver is 300 revolutions per minute, the speed of the follower 1200, and its diameter 6 inches. What must be the diameter of the driver?

85 *Solution.* $1200 \times 6 = 7200$.

$7200 \div 300 = 24$ inches, the diameter of the driver.

86 *Direction of Rotation of Pulleys.* With an open belt as in Fig. 311 the follower pulley runs in the same direction as

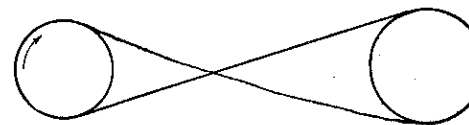


Fig. 314.

the driver, but if the belt is crossed as shown in Fig. 314, then the follower runs in the opposite direction to the driver. Where the driver is large and the follower small, more

power can be transmitted with a crossed belt than with an open one, because the arc of contact of the belt on the follower pulley will be considerably greater in the former case than in the latter.

- 87 *Toothed Gearing.* The rules just given for calculating the speed and size of belt pulleys may be made to apply equally well to toothed gears if the words *number of teeth* be substituted for *diameter* in each of the preceding rules.

QUESTIONS FOR PART XVI.

1. What is a machine?
2. Of what advantage is a machine?
3. Describe each of the three classes of levers.
4. State the "Law of Levers."
5. Show by sketch how, with the use of two pulleys, it may be possible to lift a weight of 300 pounds with 100 pounds of force.
6. State a rule for finding the force required to lift a weight with any system of pulleys.
7. State the rule given for the inclined plane.
8. What is short lap belting?
9. Which side of a belt should be run next to the pulley? Give reasons.
10. How much power will an eight-inch belt running 2500 feet per minute transmit?
11. How are the ends of belts fastened? Where would you use a hinge lacing?
12. What precautions should be taken in preparing the ends of a belt for lacing?
13. How should leather belts be cared for?
14. Why are belt pulleys made crowning?
15. If the diameter of the driver pulley is 40 inches, the diameter of the follower 10 inches, and the speed of the driver 250 revolutions, how fast will the follower run?

CLARKE SCHOOL OF TRACTION ENGINEERING.

16. If the fly wheel of an engine is 36 inches in diameter, and the pulley on the cylinder of the separator is 10 inches, how fast must the engine run to make the cylinder run at 1100 revolutions per minute?

17. If the drive gear has 60 teeth and makes 200 revolutions per minute, how many teeth must the follower have to run at 480 revolutions per minute?

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