100

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E. B. McCORMICK, Consulting Editor

FARM MOTORS

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STEAM AND GAS ENGINES
HYDRAULIC AND ELECTRIC MOTORS
WINDMILLS

BY

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PREFACE

In preparing this book it has been the intention to include the fundamental principles governing the construction, working and management of motors which are suitable for farm use. The motors treated include steam engines, gas and oil engines, traction engines, automobiles, water motors, windmills and electric motors.

The method followed in each chapter was to give:

1. the fundamental principles underlying the particular motor,
2. the principal parts of the motor,
3. auxiliary parts,
4. uses to which the particular type of motor is adapted,
5. selection, erection and management of the different machines.

While this book was prepared primarily as a text-book for students in agricultural engineering, the subject matter is so presented that it will be of equal value to farmers and to operators of various kinds of engines and motors. Much practical information is included regarding steam, gas and electricity, and the text is illustrated with over 275 cuts.

Some space is devoted to the more refined methods used in engineering practice for improving the economy of various motors. While many of these methods are not used at the present time in connection with farm motors, it is the opinion of the author that a knowledge of the best engineering practice is not only of considerable educational value, but will lead to the more perfect manipulation of the simple farm motors.

The successful rural engineer of the near future will be the man that applies proven engineering to the machinery and constructions used on the farm.

The author is particularly indebted in the preparation of this book to Professors E. B. McCormick, M. R. Bowerman, R. A. Seaton, and W. W. Carlson, of the Kansas State Agricultural College; to Professors Allen & Bursley of the University of Michigan; and to Mr. S. Yesner of Boston, Mass.

A. A. Potter.

Manhattan, Kansas,
November, 1913.

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FARM MOTORS

CHAPTER I

FARM MOTORS IN GENERAL

A motor is an apparatus capable of doing work. Not considering animal motors, which include men, horses and other animals, the mechanical motors available for farm use are: heat engines, including steam, gas or oil, hot-air and solar engines; pressure engines such as water wheels and water motors; wind-mills; electric motors.

Sources of Energy.—The principal source of all energy are the rays of the sun. They causes the growth of plants which furnish food and feed for man and animals. The great coal deposits are only the result of the storing up of the sun's rays in plants in by-gone days. These rays are also responsible for the raising of water from sea level to mountain top, thus giving it energy which can be utilized to turn water wheels and made to do useful work.

On the other hand, while the sun's rays are the fundamental sourse of all energy they can be utilized directly by man only to a very limited extent. The secondary sources of energy are the wind, waterfalls, carbon in different forms, such as coal, petroleum or gas, and chemicals used in electric batteries.

Principles Governing the Action of Various Motors.—All motors do work by virtue of motion given to a piston, blades on a wheel or to an armature by some substance such as water, steam, gas, air or electricity. The first requirement is that the above-mentioned substance, often called the working substance, be under considerable pressure.

This pressure in the case of the water motor or water wheel is obtained by collecting water in dams and tanks, or by utilizing the kinetic energy of natural water-falls. The total power available in water when in motion depends on the weight of water discharged in a given time, and on the head or distance through which the water is allowed to fall. The head of water can be utilized by its weight or pressure acting directly on a piston or on blades or paddles on wheels.

Considering next the various forms of heat engines, work is accomplished by steam or gas under pressure, this pressure being obtained by utilizing the heat of some fuel or of the rays of the sun.

A motor utilizing the heat of the sun is called a solar motor or a solar engine. The action of this type of motor depends on the vaporization of water into steam by means of the rays of the sun, which are concentrated and intensified by means of reflecting surfaces.

In the case of the steam engine a fuel like coal, oil or gas is burned in a furnace and its heat of combustion is utilized in changing water into steam, at high pressure, in a special vessel called a boiler. This high-pressure steam is then conveyed by pipes to the engine cylinder where its energy is expended in pushing a piston as in the case of the reciprocating engine. The sliding motion of the piston may be changed into rotary motion at the shaft by the interposition of a connecting rod and crank. Another method is to allow the high-pressure steam to escape through a nozzle, strike blades on a wheel and produce rotary motion direct, as in the case of the steam turbine.

In another type of heat engine, called a hot-air engine, air is heated in a cylinder by a fuel which is burned outside of the engine cylinder, and by its expansion drives a piston and thus does work.

In the case of gas and oil engines the fuel, which must be in a gaseous form as it enters the engine cylinder, is mixed with air in the proper proportions to form an explosive mixture. It is then compressed and ignited within the cylinder of the engine, the high pressures produced by the explosion pushing on a piston and doing work. These engines belong to a class called internal-combustion engines, and differ from the steam and hot-air engines, which are sometimes called external-combustion engines, in that the fuel with air is burned inside the engine cylinder, instead of in an auxiliary apparatus.

The wind-mill derives its high pressure for doing work from the moving atmosphere.

The electric motor converts electrical energy at high pressure into work; this electrical pressure or voltage being produced in an apparatus called an electrical dynamo, or generator.

Comparison of Various Types of Motors.—The solar motor is but little used on account of its high first cost and great bulk in relation to the small power developed.

In localities where the wind is abundant and little power is needed, the wind-mill is the most desirable and cheapest power. The greatest application of wind-mills is for the pumping of water for residences and farms, and for such other work as does not suffer from suspension during calm weather. Electric storage and lighting on a small scale from the power of a wind-mill has been tried in several places with fair success, but will probably not be adapted to any great extent on account of the high first cost of such an installation.

The water motor or water turbine is very economical if a plentiful supply of water can be had at a fairly high head, but its reliability is affected by drought, floods and ice in the water supply.

The hot-air engine, while not economical in fuel consumption, is well adapted for pumping water in places where the cost of fuel is not an important item and where safety and simplicity of mechanism are essential.

Of the other forms of heat engines, the internal combustion engine, whether using gas or oil, is well adapted for small and medium size powers, such as for farm use and irrigation work.

For the generation of electricity and in large sizes the steam engine or steam turbine will be found more suitable on account of their lower first cost and greater reliability.

If a source of electric current is available at a low price, the electric motor is very desirable, as it requires little care and can be bought in sizes to suit all requirements.

CHAPTER II

FUNDAMENTAL PRINCIPLES AND DEFINITIONS

Before a study is made of any motor, the fundamental conceptions of physics regarding states of matter, work, power and heat are essential.

Matter.—Matter is that which occupies space and, when limited in amount, it is called a body. Matter in any form consists of a great many small particles, called molecules, the relative position of which determines the state in which a substance exists.

States of Matter.—Matter exists in the solid, liquid and gaseous states.

In the case of the solid the relative positions of the molecules are fixed. A solid having a certain shape or form, whether due to natural or artificial causes, will retain that form, unless and until it is made to change same by some external cause.

In the case of the liquid, the relative position of the various molecules is not fixed. The shape or form of a liquid depends, therefore, on the solid walls surrounding it, a liquid assuming the form of any vessel in which it may be placed.

In the case of a gas the various molecules struggle to occupy greater space. A gas can be greatly compressed by an external force, and will expand to an unlimited extent, if it is given perfect freedom.

Motion.—Motion means change of place. If a definite amount of matter, called a body, is removed from one place to another, motion is produced.

Force and Pressure.—Anything which produces or tends to produce, modifies or tends to modify motion is called force. Force is measured in pounds. Pressure is the intensity of force and is equal to the total force divided by the area over which it acts. For example a force of 1000 lb. acting on a body whose dimensions are 5 in. by 2 in., will produce a pressure or intensity of force equal to the force divided by the area of the body in square inches, or $\frac{1000}{10} = 100$ lb. In English and American practice, pressure is always expressed in pounds per square inch. Thus when a steam gage on a boiler is registering 80 lb., this means that the steam is capable of transmitting a force of 80 lb. for every square inch on which it acts. If it is allowed to act on a 12-in. piston, the area of which is 113 sq. in., the total force exerted on the piston is 80 times 113, or 9040 lb.

The pressure exerted by the atmosphere is called barometric pressure. The barometric pressure is 14.7 lb. per square inch at sea level and decreases as the altitude, or the height of the surface of the earth above sea level, increases. For each 2000 ft. in elevation the pressure of the atmosphere is decreased by about 1 lb.

Work, Energy and Power.—Work means force times distance through which it acts and is independent of time. If a body of 1 lb. is raised through a distance of 1 ft., the resulting work is 1 ft.-lb.

The capacity for doing work is called energy. Energy existing in a body at rest, as in the case of the raised weight, is called potential energy. Energy possessed by a body when in motion is called kinetic energy.

As an illustration, a cubic foot of water, weighing 62.5 lb. when at rest at a height of 100 ft., has potential energy of 6250 ft.-lb. and this potential energy is changed into kinetic energy of work when the water is allowed to fall through that height. The water in the above example when allowed to fall through10 ft. will be capable, on account of its kinetic energy, to do 625 ft.-lb. of work and will have a potential energy of 6250 − 625, or 5625 ft.-lb. when it comes again to rest.

Power takes into consideration the time it takes to do a certain amount of work and is defined as the rate of doing work. Thus if steam at a pressure of 100 lb. moves a piston 18 in. in diameter through a distance of 2 ft., the work done is 100 times 254.46 (the area of the piston in inches multiplied by the distance in feet) or 25,446 ft.-lb. The power of the engine, however, depends on the time that the steam requires to move the piston through the given distance and, if the motion is accomplished in one second, the power of the engine is five times greater than if five seconds were required.

Horse-power.—If work is done at the rate of 33,000 ft.-lb. per minute, 1 h.p. is said to be exerted. This means that an engine will have a capacity of 1 h.p. if it can do 550 ft.-lb. of work in a second, 33,000 ft.-lb. of work in a minute or 1,980,000 ft.-lb. of work in an hour. In the example of the previous paragraph if the piston passes through the distance of 2 ft. in one-fiftieth of a minute, the power of the engine in horse-power is

$$\frac{25{,}546\times 2}{33{,}000\times \frac{1}{50}}=77.4$$

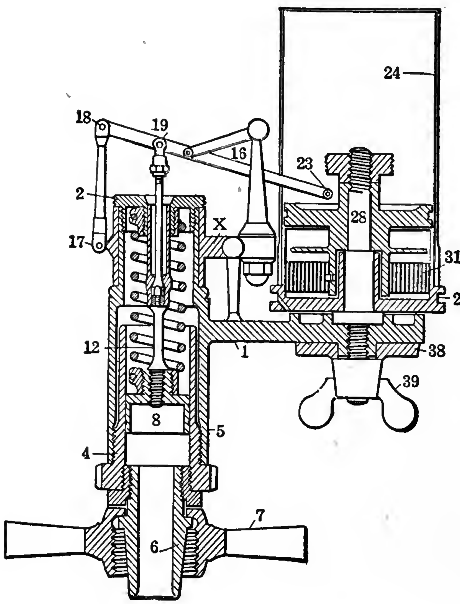


Fig. 1.

It is important to remember that power takes into consideration work and time. All animals, including man, are able to produce more power for a short period of time, while mechanical motors, whether driven by water, wind, steam, gas or electricity can exert, with proper care, the power for which they are designed for an indefinite length of time.

Indicated Horse-power.—The term indicated horse-power (i.h.p.) is applied to the rate of doing work by steam or by a gas in the cylinder of an engine, and is obtained by means of a special instrument, called an indicator. One form of this type of instrument, the Crosby, is shown in section in Fig. 1. It consists essentially of a cylinder 4, which is placed in direct communication with the engine cylinder, and in which moves a piston 8 compressing a spring above it and raising the arm 16. At the end of the arm is a pencil 23 which records graphically the pressure of the steam in the engine cylinder on the revolving drum 24. This drum 24 is covered with paper and receives its motion from the engine cross-head. From the diagram drawn on the drum of the indicator, the average pressure is determined, and the horse-power is calculated from this and from dimensions and speed of the engine.

As an illustration, if the average unbalanced pressure of the steam on the piston, as obtained by means of an indicator, and called the mean effective pressure, is 40 lb. for a 12-in.×13-in. steam engine running at 250 r.p.m., the total pressure exerted by the steam on a 12-in. piston is

$$40 \times 113.1 = 4524 \text{ lb.}$$

Since the stroke is 13 in., the work done in one end in foot-pounds per revolution is

$$4524 \times \frac{13}{12} = 4901$$

The engine making 250 r.p.m., the work per minute will be

$$4901 \times 250 = 1{,}225{,}250 \text{ ft.-lb.}$$

Since 33,000 ft.-lb. per minute is 1 h.p., the power of the engine is:

$$\frac{1{,}225{,}250}{33{,}000} = 37.1 \text{ i.h.p.}$$

As steam engines are usually double acting, an indicator card would have to be taken of the crank end, the mean effective pressure determined for that end and the indicated horse-power calculated by the above method, taking into consideration the size of the piston rod. The total indicated horse-power of the engine is the sum of that calculated for the two ends.

Brake Horse-power.—Brake horse-power represents the actual power which a motor or engine can deliver for the purpose of work at a shaft or a brake. An instrument for the measurement of the brake horse-power of motors, and called a Prony Brake, is shown in Fig. 2. It consists of two wooden blocks BB which fit around the pulley P and are tightened by means of the thumb nuts NN. A projection of one of the blocks, the lever L, rests on the platform scales S. When the brake is balanced, the power absorbed is measured by the weight as registered on the scales multiplied by the distance it would pass through in that time if free to move. If l is the length of the brake arm in feet, w the weight as registered on the scales in pounds and n the revolutions per minute of the motor, the horse-power absorbed can be calculated by the formula

$$\text{Brake horse-power} = \frac{2\pi lwn}{33{,}000}$$

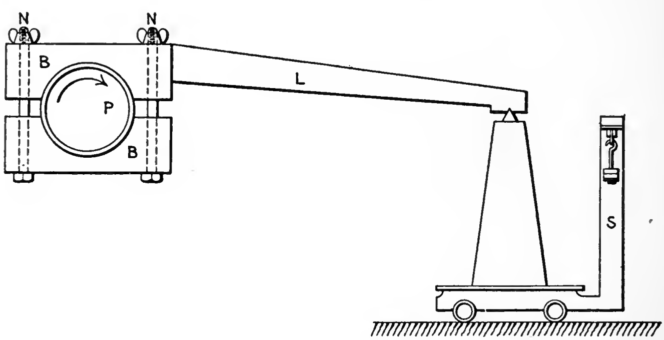


Fig. 2.

As an illustration, the scale reading of an engine running at 250 r.p.m. is 80 lb. If the length of the brake arm is $5\frac{1}{4}$ ft., calculate the brake horse-power developed.

$$\text{Brake horse-power} = \frac{2 \times 3.1416 \times 5.25 \times 80 \times 250}{33{,}000} = 19.04$$

Nature of Heat.—Heat is a form of energy and not a material substance. The heat of a body depends on the vibratory motion of the particles or molecules of which the body is built up, the greater the rate of motion of these molecules the higher is the temperature of the body.

Temperature.—Temperature indicates the relative heats of bodies, or the relative rate of motion of the molecules in bodies. Temperature is not a measure of the amount or quantity of heat in a body. Thus a small and a large piece of metal may be heated to the same temperature, but the large piece would possess the greater quantity of heat. Temperature is an indication of the sensible heat of a substance, or the heat intensity which can be revealed to the senses of an observer.

Thermometers.—A thermometer is an instrument by means of which the temperature of a substance is measured. As usually constructed, it consists of a liquid such as mercury or alcohol enclosed in a bulb at one end of a thin glass tube, the temperature changes producing sufficient variations in the expansion of the liquid as can be read off on a scale attached to, or graduated, on the glass tube.

Thermometers are graduated in three different ways, which are called the three thermometric scales, the type of scale depending on the number of graduations, or degrees (° denotes degree) between the melting-point of ice and the boiling-point of water.

The scale mostly used in English-speaking countries is the Fahrenheit (F.). In this case the melting-point of ice is taken at 32° and the boiling-point of water at 212°. Thus the Fahrenheit degree (° F.) is 1/180 of the interval between the two fixed points.

In scientific work the Centigrade scale is used in most countries. The centigrade degree is 1/100 of the temperature interval between the melting-point of ice and the boiling-point of water, these two fixed points being denoted 0° C. and 100° C. respectively.

Another scale, used only to a limited extent in certain countries of Europe is the Reaumur scale which has the melting-point of ice at 0° R. and the boiling-point of water at 80° R.

The relations existing between the thermometric scales mostly used, *i.e.*, the Fahrenheit (F.) and the Centigrade (C.) can be expressed:

$$\text{degrees } C. = 5/9\ (\text{degrees F.} - 32)$$

$$\text{degrees } F. = 9/5 \text{ degrees C.} + 32$$

Example: Convert 15° C. to the Fahrenheit scale and 400° F. to the Centigrade scale.

$$\text{degrees F.} = 9/5 \times \text{degrees C.} + 32$$
$$= 9/5 \times 15 + 32$$
$$= 27 + 32 = 59° \text{ F.}$$
$$\text{degrees C.} = 5/9 \ (\text{degrees F.} - 32)$$
$$= 5/9 \ (400 - 32)$$
$$= 204° \text{ C.}$$

Table 1 can be used for converting Centigrade into Fahrenheit degrees and conversely.

TABLE 1.—RELATION BETWEEN THE FAHRENHEIT AND CENTIGRADE THERMOMETRIC SCALES

Fahr.	Cent.	Fahr.	Cent.
−30	−34.4	210	98.9
−20	−28.9	212	100.0
−10	−23.3	220	104.4
0	−17.8	230	110.0
+10	−12.2	240	119.6
20	− 6.7	250	121.1
30	− 1.1	260	126.7
32	0.0	270	132.2
40	+ 4.4	280	137.8
50	10.0	290	143.3
60	15.6	300	148.9
70	21.1	310	154.4
80	26.7	320	160.0
90	32.2	330	165.6
100	37.8	340	171.1
110	43.3	350	176.7
120	48.9	360	182.2
130	54.4	370	187.8
140	60.0	380	193.3
150	65.6	390	198.9
160	71.1	400	204.4
170	76.7	410	210.0
180	82.2	420	215.6
190	87.8	430	221.1
200	93.3	440	226.7

Units of Heat.—Heat is measured in heat units. A heat unit is the amount of heat required to raise the temperature of one pound of water one degree. The heat unit used in English speaking countries is the British Thermal Unit (B.t.u.). The B.t.u. is defined as the amount of heat required to raise one pound of water from 62° F. to 63° F.

When a certain illuminating gas is said to contain 600 B.t.u., this means that each cubic foot of the gas is capable of raising the temperature of 10 lb. of water through 60° F., or that it will raise the temperature of water so that the product of the weight of water and temperature rise (in ° F.) is 600.

Mechanical Equivalent of Heat.—It was proved experimentally that heat and work are mutually convertible. It requires 778 ft.-lb. of work to produce 1 B.t.u.; and similarly 1 B.t.u. will produce 778 ft.-lb. of work, if all the heat is converted into work. 778 is called the mechanical equivalent of heat. It is due to the fact that heat can be converted into work that the various heat engines, including the steam, gas and oil engines are possible.

Specific Heat.—As the addition of the same quantity of heat

TABLE 2.—SPECIFIC HEATS AND SPECIFIC GRAVITIES OF COMMON SUBSTANCES

Name of substance	Specific heat (average)	Specific gravity (average)
Solids		
Iron, cast	0.1298	7.21
Iron, wrought	0.1138	7.70
Steel	0.1170	7.80
Lead	0.0314	11.4
Copper	0.0951	8.90
Glass	0.170	2.60
Ice	0.504	0.90
Stone	0.21	2.75
Brick work, masonry	0.20	2.00
Liquids		
Water	1.000	1.000
Kerosene	0.475	0.810
Gasoline	0.535	0.690
Alcohol, ethyl	0.550	0.790
Alcohol, methyl	0.590	0.808
Ammonia	....	0.950
Vegetable oil	0.400	0.900
Gases		
Air	0.2375	1.000
Oxygen	0.2175	1.1052
Hydrogen	3.4090	0.0692
Nitrogen	0.2438	0.9701
Ammonia	0.508	0.5889

will not produce the same temperature changes in equal weights of different substances, it is evident that the amount of heat which can be taken in or given out by any substance depends on the capacity of that substance for heat. The capacity of a substance for heat or the resistance which a substance offers to a change in its temperature, is called its specific heat. The specific heat of water is taken as the standard and equal to one.

Specific Gravity.—By specific gravity is meant the relation existing between the weight of any substance and the weight of an equal volume or bulk of water. Thus the specific gravity of cast iron is about 7, which means that a cubic foot of iron is seven times heavier than a cubic foot of water. In Table 2 are given the specific heats and specific gravities of common substances.

PROBLEMS

1. Calculate the work done by a pump when lifting 100 gallons of water to a height of 125 ft.

2. The pressure of steam on the piston of an engine is 30 lb. If the diameter of the piston is 18 in., its stroke 2 ft., how much work does the engine do per hour if its speed is 110 r.p.m.?

3. Calculate the horse-power of the engine in the above problem.

4. A mine cage weighing 3000 lb. is to be lifted up a 750-ft. shaft in 1/2 minute. Calculate the horse-power of the motor required, allowing 20 per cent. for losses.

5. Calculate the horse-power of a traction engine required to draw a plow at the rate of 2 miles per hour if the pull on the draw bar is 15,000 lb.

6. Convert the following readings in degrees Centigrade to the Fahrenheit scale:

$$-18, -2, 15, 53, 78.$$

7. Convert the following readings on the Fahrenheit scale to degrees Centigrade:

$$-20, 10, 60, 80, 220, 350.$$

8. A pound of gasoline will yield when completely burned 19,200 heat units, calculate the foot-pounds of energy contained.

9. Calculate the heat required to raise the temperatures of cast iron, copper, glass, stone and water through 100° F.

10. Calculate and compare the weights of a gallon of kerosene, of gasoline, of ethyl alcohol, of ammonia and of water.

11. Calculate the indicated horse-power of an engine having the following dimensions:

Diameter of cylinder	16 in.
Diameter of piston rod	2 1/2 in.
Stroke	24 in.
Revolutions per minute	120
Mean effective pressure, head end	52.3
Mean effective pressure, crank end	52.0

12. A gasoline engine running at 300 r.p.m. is tested by means of a Prony brake. If the length of the brake arm is 42 in. and the net weight as registered on the platform scales is 35 lb., calculate the brake horse-power developed by the engine.

CHAPTER III

STEAM, FUELS AND COMBUSTION

Theory of Steam Generation.—If heat is added to ice, the effect will be to raise its temperature until the thermometer indicates 32° F. When this point is reached, a further addition of heat does not produce an increase in temperature until all the ice is changed into water, or in other words melts. It has been found experimentally that 144 B.t.u. are required to change 1 lb. of ice into water. This quantity is called the latent heat of liquefaction of ice.

After the quantity of ice given, which for simplicity may be taken as 1 lb., has all been turned into water, it will be found that if more heat is added the temperature of the water will again increase, though not as rapidly as did that of the ice. While the addition of each British thermal unit increases the temperature of ice 2° F., in the case of water an increase of only about 1° will be noticed for each British thermal unit of heat added. This difference is due to the fact that the specific heat, or resistance offered by ice to a change in temperature is one-half that offered by water. That is, the specific heat of ice is 0.5.

If the water is heated in a vessel open to the atmosphere, its temperature will keep on going up until about 212° F., the boiling-point of water, when further addition of heat will not produce any temperature changes, but steam will issue from the vessel. It has been found that about 970 B.t.u. will be required to change a pound of water at atmospheric pressure and at 212° F. into steam. The quantity of heat so supplied which changes the physical state of water from the liquid state to steam is called the latent heat of vaporization.

If the above operations are performed in a closed vessel, water will boil at a higher temperature than 212° F., since the steam driven off cannot escape and is compressed, raising the pressure and consequently the temperature. The latter is the condition in an ordinary steam boiler.

That the boiling-point of water depends on the pressure is well known. Thus in a place in Colorado where the altitude is 6000 ft. above sea level and the barometric pressure is 12.6 lb. per square inch the boiling-point of water is about 204° F. as compared with 212° F. at sea level where the barometric pressure is 14.7 lb. per square inch.

As the pressure is increased to 60 lb. per square inch by the gage, it will be found that the boiling-point of water is 275° F. At 100 lb. per square inch water will boil at 317° F. and at 150 lb. the temperature will read 350.5° F. before steam will be formed.

Steam is spoken of as being in three conditions:

1. Wet.
2. Dry and saturated.
3. Superheated.

In the first case the steam carries with it a certain amount of water which has not been evaporated. The percentage of this water determines the condition of the steam; that is, if there is 3 per cent. by weight of moisture, the steam is spoken of as being 97 per cent. dry. A stationary boiler, properly erected and operated and of suitable size, should generate steam that is 98 per cent. dry. If there is more than 3 per cent. moisture, there is every reason to believe that the boiler is improperly installed, inefficiently operated, or is too small for the work to be done.

The second condition, that of dry and saturated, may be considered the standard for steam. In this case the steam carries with it no water that has not been evaporated, that is, it is dry, and has a temperature corresponding with its pressure. Any loss of heat, however small, not accompanied by a corresponding reduction in pressure, will cause condensation, and wet steam will be the result. It is because of this property that this condition of the steam is designated as saturated as well as dry.

An increase in temperature not accompanied by an increase in pressure will cause the steam to acquire a condition that will permit a loss of heat at constant pressure without condensation necessarily following. This third condition is called superheat. The advantage of superheated steam lies in the fact that its temperature may be reduced by the amount of the superheat without causing condensation. This makes it possible to transmit the steam through mains and still have it dry and saturated at the time it reaches the engine cylinder.

The pressure of steam will remain constant if it is used as fast as it is generated. If an engine uses steam too rapidly the boiler pressure will drop and similarly if the fuel is burned at a constant rate and an insufficient amount of steam is used the pressure of the steam in the boiler will increase.

In Table 3 are given some of the most important properties of saturated steam which include:

1. Pressure of steam in pounds per square inch absolute.
2. Temperatures of steam in degrees Fahrenheit. This column of temperatures shows the vaporization temperature at each of the given pressures.
3. Heat of the liquid, or the heat required to bring up a pound of water from freezing-point to boiling-point.
4. The latent heat, or the heat required to vaporize a pound of water at the given pressure after boiling-point is reached.
5. The volume of 1 lb. of steam at the various pressures.
6. Density of steam in pounds per cubic foot.

Fuels.—The fuels most commonly used for steam generation are coal, wood, petroleum oils and natural gas. The combustible, or heat-producing, constituents of all fuels are carbon and hydrogen. A fuel containing much sulphur should be avoided

TABLE 3.—PROPERTIES OF SATURATED STEAM

ENGLISH UNITS

Abs. Pressure Pounds per Sq. in.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
.0886	32	0	1072.6	1072.6	3301.0	.000303	.0886
.2562	60	28.1	1057.4	1085.5	1207.5	.000828	.2562
.5056	80	48.1	1046.6	1094.7	635.4	.001573	.5056
1	101.8	69.8	1034.6	1104.4	333.00	.00300	1
2	126.1	94.1	1021.4	1115.5	173.30	.00577	2
3	141.5	109.5	1012.3	1121.8	118.50	.00845	3
4	153.0	120.9	1005.6	1126.5	90.50	.01106	4
5	162.3	130.2	1000.2	1130.4	73.33	.01364	5
6	170.1	138.0	995.7	1133.7	61.89	.01616	6
7	176.8	144.8	991.6	1136.4	53.58	.01867	7
8	182.9	150.8	988.0	1138.8	47.27	.02115	8

TABLE 3.—PROPERTIES OF SATURATED STEAM—*Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
9	188.3	156.3	984.8	1141.1	42.36	.02361	9
10	193.2	161.2	981.7	1142.9	38.38	.02606	10
11	197.7	165.8	978.9	1144.7	35.10	.02849	11
12	202.0	170.0	976.3	1146.3	32.38	.03089	12
13	205.9	173.9	973.9	1147.8	30.04	.03329	13
14	209.6	177.6	971.6	1149.2	28.02	.03568	14
14.7	212.0	180.1	970.0	1150.1	26.79	.03733	14.7
15	213.0	181.1	969.4	1150.5	26.27	.03806	15
16	216.3	184.5	967.3	1151.8	24.77	.04042	16
17	219.4	187.7	965.3	1153.0	23.38	.04277	17
18	222.4	190.6	963.4	1154.0	22.16	.04512	18
19	225.2	193.5	961.5	1155.0	21.07	.04746	19
20	228.0	196.2	959.7	1155.9	20.08	.04980	20
21	230.6	198.9	958.0	1156.9	19.18	.05213	21
22	233.1	201.4	956.4	1157.8	18.37	.05445	22
23	235.5	203.9	954.8	1158.7	17.62	.05676	23
24	237.8	206.2	953.2	1159.4	16.93	.05907	24
25	240.1	208.5	951.7	1160.2	16.30	.0614	25
26	242.2	210.7	950.3	1161.0	15.71	.0636	26
27	244.4	212.8	948.9	1161.7	15.18	.0659	27
28	246.4	214.9	947.5	1162.4	14.67	.0682	28
29	248.4	217.0	946.1	1163.1	14.19	.0705	29
30	250.3	218.9	944.8	1163.7	13.74	.0728	30
31	252.2	220.8	943.5	1164.3	13.32	.0751	31
32	254.1	222.7	942.2	1164.9	12.93	.0773	32
33	255.8	224.5	941.0	1165.5	12.57	.0795	33
34	257.6	226.3	939.8	1166.1	12.22	.0818	34
35	259.3	228.0	938.6	1166.6	11.89	.0841	35
36	261.0	229.7	937.4	1167.1	11.58	.0863	36
37	262.6	231.4	936.3	1167.7	11.29	.0886	37
38	264.2	233.0	935.2	1168.2	11.01	.0908	38
39	265.8	234.6	934.1	1168.7	10.74	.0931	39
40	267.3	236.2	933.0	1169.2	10.49	.0953	40
41	268.7	237.7	931.9	1169.6	10.25	.0976	41
42	270.2	239.2	930.9	1170.1	10.02	.0998	42
43	271.7	240.6	929.9	1170.5	9.80	.1020	43
44	273.1	242.1	928.9	1171.0	9.59	.1043	44
45	274.5	243.5	927.9	1171.4	9.39	.1065	45
46	275.8	244.9	926.9	1171.8	9.20	.1087	46

TABLE 3.—PROPERTIES OF SATURATED STEAM—*Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	*t*	*h*	*L*	*H*	*v*	$\frac{1}{v}$	*p*
47	277.2	246.2	926.0	1172.2	9.02	.1109	47
48	278.5	247.6	925.0	1172.6	8.84	.1131	48
49	279.8	248.9	924.1	1173.0	8.67	.1153	49
50	281.0	250.2	923.2	1173.4	8.51	.1175	50
51	282.3	251.5	922.3	1173.8	8.35	.1197	51
52	283.5	252.8	921.4	1174.2	8.20	.1219	52
53	284.7	254.0	920.5	1174.5	8.05	.1241	53
54	285.9	255.2	919.6	1174.8	7.91	.1263	54
55	287.1	256.4	918.7	1175.1	7.78	.1285	55
56	288.2	257.6	917.9	1175.5	7.65	.1307	56
57	289.4	258.8	917.1	1175.9	7.52	.1329	57
58	290.5	259.9	916.2	1176.1	7.40	.1351	58
59	291.6	261.1	915.4	1176.5	7.28	.1373	59
60	292.7	262.2	914.6	1176.8	7.17	.1394	60
61	293.8	263.3	913.8	1177.1	7.06	.1416	61
62	294.9	264.4	913.0	1177.4	6.95	.1438	62
63	295.9	265.5	912.2	1177.7	6.85	.1460	63
64	297.0	266.5	911.5	1178.0	6.75	.1482	64
65	298.0	267.6	910.7	1178.3	6.65	.1503	65
66	299.0	268.6	910.0	1178.6	6.56	.1525	66
67	300.0	269.7	909.2	1178.9	6.47	.1547	67
68	301.0	270.7	908.4	1179.1	6.38	.1569	68
69	302.0	271.7	907.7	1179.4	6.29	.1591	69
70	302.9	272.7	906.9	1179.6	6.20	.1612	70
71	303.9	273.7	906.2	1179.9	6.12	.1634	71
72	304.8	274.6	905.5	1180.1	6.04	.1656	72
73	305.8	275.6	904.8	1180.4	5.96	.1678	73
74	306.7	276.6	904.1	1180.7	5.89	.1699	74
75	307.6	277.5	903.4	1180.9	5.81	.1721	75
76	308.5	278.5	902.7	1181.2	5.74	.1743	76
77	309.4	279.4	902.1	1181.5	5.67	.1764	77
78	310.3	280.3	901.4	1181.7	5.60	.1786	78
79	311.2	281.2	900.7	1181.9	5.54	.1808	79
80	312.0	282.1	900.1	1182.2	5.47	.1829	80
81	312.9	283.0	899.4	1182.4	5.41	.1851	81
82	313.8	283.8	898.8	1182.6	5.34	.1873	82
83	314.6	284.7	898.1	1182.8	5.28	.1894	83
84	315.4	285.6	897.5	1183.1	5.22	.1915	84
85	316.3	286.4	896.9	1183.3	5.16	.1937	85

TABLE 3.—PROPERTIES OF SATURATED STEAM—*Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
86	317.1	287.3	896.2	1183.5	5.10	.1959	86
87	317.9	288.1	895.6	1183.7	5.05	.1980	87
88	318.7	288.9	895.0	1183.9	5.00	.2002	88
89	319.5	289.8	894.3	1184.1	4.94	.2024	89
90	320.3	290.6	893.7	1184.3	4.89	.2045	90
91	321.1	291.4	893.1	1184.5	4.84	.2066	91
92	321.8	292.2	892.5	1184.7	4.79	.2088	92
93	322.6	293.0	891.9	1184.9	4.74	.2110	93
94	323.4	293.8	891.3	1185.1	4.69	.2131	94
95	324.1	294.5	890.7	1185.2	4.65	.2152	95
96	324.9	295.3	890.1	1185.4	4.60	.2173	96
97	325.6	296.1	889.5	1185.6	4.56	.2194	97
98	326.4	296.8	889.0	1185.8	4.51	.2215	98
99	327.1	297.6	888.4	1186.0	4.47	.2237	99
100	327.8	298.4	887.8	1186.2	4.430	.2257	100
101	328.6	299.1	887.2	1186.3	4.389	.2278	101
102	329.3	299.8	886.7	1186.5	4.349	.2299	102
103	330.0	300.6	886.1	1186.7	4.309	.2321	103
104	330.7	301.3	885.6	1186.9	4.270	.2342	104
105	331.4	302.0	885.0	1187.0	4.231	.2364	105
106	332.0	302.7	884.5	1187.2	4.193	.2385	106
107	332.7	303.4	883.9	1187.3	4.156	.2407	107
108	333.4	304.1	883.4	1187.5	4.119	.2428	108
109	334.1	304.8	882.8	1187.6	4.082	.2450	109
110	334.8	305.5	882.3	1187.8	4.047	.2472	110
111	335.4	306.2	881.8	1188.0	4.012	.2493	111
112	336.1	306.9	881.2	1188.1	3.977	.2514	112
113	336.8	307.6	880.7	1188.3	3.944	.2535	113
114	337.4	308.3	880.2	1188.5	3.911	.2557	114
114.7	337.9	308.8	879.8	1188.6	3.888	.2572	114.7
115	338.1	309.0	879.7	1188.7	3 878	.2578	115
116	338.7	309.6	879.2	1188.8	3.846	.2600	116
117	339.4	310.3	878.7	1189.0	3.815	.2621	117
118	340.0	311.0	878.2	1189.2	3.784	.2642	118
119	340.6	311.7	877.6	1189.3	3.754	.2663	119
120	341.3	312.3	877.1	1189.4	3.725	.2684	120
121	341.9	313.0	876.6	1189.6	3.696	.2706	121
122	342.5	313.6	876.1	1189.7	3.667	.2727	122
123	343.2	314.3	875.6	1189.9	3.638	.2749	123

TABLE 3.—PROPERTIES OF SATURATED STEAM—*Continued*
ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	*t*	*h*	*L*	*H*	*v*	$\frac{1}{v}$	*p*
124	343.8	314.9	875.1	1190.0	3.610	.2770	124
125	344.4	315.5	874.6	1190.1	3.582	.2792	125
126	345.0	316.2	874.1	1190.3	3.555	.2813	126
127	345.6	316.8	873.7	1190.5	3.529	.2834	127
128	346.2	317.4	873.2	1190.6	3.503	.2855	128
129	346.8	318.0	872.7	1190.7	3.477	.2876	129
130	347.4	318.6	872.2	1190.8	3.452	.2897	130
131	348.0	319.3	871.7	1191.0	3.427	.2918	131
132	348.5	319.9	871.2	1191.1	3.402	.2939	132
133	349.1	320.5	870.8	1191.3	3.378	.2960	133
134	349.7	321.0	870.4	1191.4	3.354	.2981	134
135	350.3	321.6	869.9	1191.5	3.331	.3002	135
136	350.8	322.2	869.4	1191.6	3.308	.3023	136
137	351.4	322.8	868.9	1191.7	3.285	.3044	137
138	352.0	323.4	868.4	1191.8	3.263	.3065	138
139	352.5	324.0	868.0	1192.0	3.241	.3086	139
140	353.1	324.5	867.6	1192.1	3.219	.3107	140
141	353.6	325.1	867.1	1192.2	3.198	.3128	141
142	354.2	325.7	866.6	1192.3	3.176	.3149	142
143	354.7	326.3	866.2	1192.5	3.155	.3170	143
144	355.3	326.8	865.8	1192.6	3.134	.3191	144
145	355.8	327.4	865.3	1192.7	3.113	.3212	145
146	356.3	327.9	864.9	1192.8	3.093	.3233	146
147	356.9	328.5	864.4	1192.9	3.073	.3254	147
148	357.4	329.0	864.0	1193.0	3.053	.3275	148
149	357.9	329.6	863.5	1193.1	3.033	.3297	149
150	358.5	330.1	863.1	1193.2	3.013	.3319	150
152	359.5	331.2	862.3	1193.5	2.975	.3361	152
154	360.5	332.3	861.4	1193.7	2.939	.3403	154
156	361.6	333.4	860.5	1193.9	2.903	.3445	156
158	362.6	334.4	859.7	1194.1	2.868	.3487	158
160	363.6	335.5	858.8	1194.3	2.834	.3529	160
162	364.6	336.6	858.0	1194.6	2.801	.3570	162
164	365.6	337.6	857.2	1194.8	2.768	.3613	164
166	366.5	338.6	856.4	1195.0	2.736	.3655	166
168	367.5	339.6	855.5	1195.1	2.705	.3697	168
170	368.5	340.6	854.7	1195.3	2.674	.3739	170
172	369.4	341.6	853.9	1195.5	2.644	.3782	172
174	370.4	342.5	853.1	1195.6	2.615	.3824	174
176	371.3	343.5	852.3	1195.8	2.587	.3865	176

TABLE 3.—PROPERTIES OF SATURATED STEAM—*Continued*

ENGLISH UNITS

Abs. Pressure Pounds per Sq. In.	Temperature Degrees F.	Heat of the Liquid	Latent Heat of Evaporation	Total Heat of Steam	Specific Volume Cu. Ft. per Pound	Density Pounds per Cu. Ft.	Abs. Pressure Pounds per Sq. In.
p	t	h	L	H	v	$\frac{1}{v}$	p
178	372.2	344.5	851.5	1196.0	2.560	.3907	178
180	373.1	345.4	850.8	1196.2	2.532	.3949	180
182	374.0	346.4	850.0	1196.4	2.506	.3990	182
184	374.9	347.4	849.3	1196.7	2.480	.4032	184
186	375.8	348.3	848.5	1196.8	2.455	.4074	186
188	376.7	349.2	847.7	1196.9	2.430	.4115	188
190	377.6	350.1	847.0	1197.1	2.406	.4157	190
192	378.5	351.0	846.2	1197.2	2.381	.4200	192
194	379.3	351.9	845.5	1197.4	2.358	.4242	194
196	380.2	352.8	844.8	1197.6	2.335	.4284	196
198	381.0	353.7	844.0	1197.7	2.312	.4326	198
200	381.9	354.6	843.3	1197.9	2.289	.4370	200
202	382.7	355.5	842.6	1198.1	2.268	.4411	202
204	383.5	356.4	841.9	1198.3	2.246	.4452	204
206	384.4	357.2	841.2	1198.4	2.226	.4493	206
208	385.2	358.1	840.5	1198.6	2.206	.4534	208
210	386.0	358.9	839.8	1198.7	2.186	.4575	210
212	386.8	359.8	839.1	1198.9	2.166	.4618	212
214	387.6	360.6	838.4	1199.0	2.147	.4660	214
216	388.4	361.4	837.7	1199.1	2.127	.4700	216
218	389.1	362.3	837.0	1199.3	2.108	.4744	218
220	389.9	363.1	836.4	1199.5	2.090	.4787	220
222	390.7	363.9	835.7	1199.6	2.072	.4829	222
224	391.5	364.7	835.0	1199.7	2.054	.4870	224
226	392.2	365.5	834.3	1199.8	2.037	.4910	226
228	393.0	366.3	833.7	1200.0	2.020	.4950	228
230	393.8	367.1	833.0	1200.1	2.003	.4992	230
232	394.5	367.9	832.3	1200.2	1.987	.503	232
234	395.2	368.6	831.7	1200.3	1.970	.507	234
236	396.0	369.4	831.0	1200.4	1.954	.511	236
238	396.7	370.2	830.4	1200.6	1.938	.516	238
240	397.4	371.0	829.8	1200.8	1.923	.520	240
242	398.2	371.7	829.2	1200.9	1.907	.524	242
244	398.9	372.5	828.5	1201.0	1.892	.528	244
246	399.6	373.3	827.8	1201.1	1.877	.532	246
248	400.3	374.0	827.2	1201.2	1.862	.537	248
250	401.1	374.7	826.6	1201.3	1.848	.541	250
275	409.6	383.7	819.0	1202.7	1.684	.594	275
300	417.5	392.0	811.8	1203.8	1.547	.647	300
350	431.9	407.4	798.5	1205.9	1.330	.750	350

for steam generation on account of the injurious sulphurous acid formed when the fuel is burned.

Wood is but little used for steam generation except in remote places, where timber is plentiful or in special cases where sawdust, shavings and pieces of wood are a by-product of manufacturing operations. Wood burns rapidly and with a bright flame, but does not evolve much heat. When first cut, wood contains 30 to 50 per cent. of moisture which can be reduced by drying to about 15 per cent. One pound of dry wood is equal in heat-producing value to 4/10 lb. of soft coal. It is important that-wood be dry as each 10 per cent. of moisture reduces its heat-producing value as a fuel by about 12 per cent.

Coal is more extensively used as a fuel for steam generation than any other substance. All coals are derived from vegetable origin and are classified as follows:

1. Anthracite, or hard coal consisting mainly of carbon. This coal is slow to ignite, burns with very little flame, produces and gives off very little smoke. Anthracite coal contains very little volatile matter and may contain none.

2. Semi-anthracite coal is softer and lighter than anthracite, and contains less carbon and from 7 to 12 per cent. volatile matter.

3. Semi-bituminous, which contains from 12 to 25 per cent. volatile matter and less fixed carbon than the semi-anthracite.

4. Bituminous, or soft coal contains more than 20 per cent. of volatile matter and only about 50 per cent. of fixed carbon.

5. Lignite, which may be classified as soft coal, arrested in the process of formation. This coal contains a very large proportion of volatile matter and less than 50 per cent. fixed carbon. However, it has a good heating value and is usually a free burner, but owing to the high percentage of volatile matter it will not stand storage, but crumbles badly soon after exposure to air.

Other solid fuels used to some extent for steam generation are: Peat, which is an intermediate between wood and coal and found in bogs, sawdust, spent oak bark after having been used in the process of tanning, bagasse or the refuse of cane sugar, and cotton stalks. Coke is also used to some extent, the advantage of this fuel as compared with coal being that coke will not ignite spontaneously, will not deteriorate or decompose when exposed to the atmosphere, and produces no smoke when burned. Coke is manufactured by burning coal in a limited air supply, the volatile hydrocarbons being driven off during the process.

Petroleum fuels either in the form of crude petroleum, or as the refuse left from its distillation, are used for making steam to a considerable extent in certain parts where the relative cost of oil is less than that of coal. It has been estimated that petroleum oils at 2 cents per gallon are equally economical for steam making as coal at $3 per ton. The advantages of oil as compared with solid fuels are ease of handling, cleanliness and absence of smoke after combustion.

Natural gas is used for steam generation where its cost is low. If the cost of natural gas is greater than 10 cents per thousand cubic feet it cannot compete with coal at $3 a ton. Illuminating gas is too expensive for steam generation and cannot compete with other fuels.

Combustion.—Combustion is a chemical combination of the heat producing constituents of a fuel with oxygen and is accompanied by the production of heat and light. The supply of oxygen for combustion is taken from the atmosphere, every pound of air consisting of 0.23 parts by weight of oxygen and 0.77 parts by weight of nitrogen.

It has been found that most coals require between 11 and 12 lb. of air for every pound of coal burned and that the heat developed during the combustion of 1 lb. of the various fuels is as follows:

TABLE 4.—HEAT DEVELOPED BY THE COMBUSTION OF VARIOUS FUELS

Name of fuel	Heat developed in B.t.u. per pound of fuel	Heat developed in B.t.u. per cubic foot of fuel
Anthracite coal	13,200 to 13,900	......
Semi-bituminous coal	13,000 to 16,000	......
Bituminous coal	12,000 to 15,000	......
Lignite	8,500 to 11,400	......
Peat (dry)	8,000 to 11,000	......
Wood	8,200 to 9,200	......
Petroleum fuels	18,000 to 20,000	......
Alcohol (100 per cent.)	11,500	......
Natural gas	......	900 to 1000
Illuminating gas	......	600 to 700
Producer gas	......	100 to 150

Commercial Value of Fuels.—In the furnace of the actual boiler plant only 30 to 70 per cent. of the heat units contained in the given fuel is utilized for the generation of steam. The principal losses in the boiler furnace are due to incomplete combustion, infiltration of air through setting, and to the heat carried away in the flue gases. The methods to be employed in order to reduce these losses to a minimum will be discussed under boiler management.

PROBLEMS

1. Calculate the heat contained in 1 lb. of dry steam at 100 lb. gage.

2. If the steam in the above problem contained 5 per cent. moisture, how much less heat would that pound of steam have as compared with dry steam?

3. Calculate the volume of 3 lb. of steam at atmospheric pressure, and also at a pressure of 150 lb. gage.

4. If steam at a pressure of 120 lb. has a temperature of 390° F., is it saturated?

5. Taking the weight of a gallon of water as 8 1/3 lb. and using the values given in Tables 2 and 4, compare the heat units contained in a gallon of gasoline and kerosene.

6. If a ton of ice melts in 24 hours, how much heat will it abstract during that time from the surrounding substances?

CHAPTER IV

STEAM BOILERS AND AUXILIARIES

Principal Parts of a Steam Power Plant.—The principal parts of a steam power plant are illustrated in Fig. 3, and include the following:

A furnace in whch the fuel is burned. This consists of a chamber arranged with a grate I, if coal or any other solid fuel

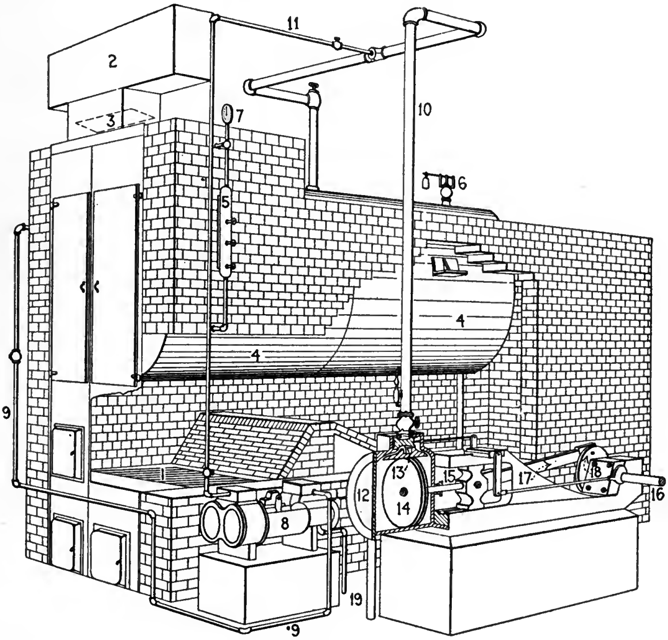


Fig. 3.

is used, and with burners when the fuel is in the liquid or gaseous state. The furnace is connected through a flue or breeching 2 to a chimney. The function of a chimney is to produce sufficient draft, so that the fuel will have the proper amount of air for combustion; it also serves to carry off the obnoxious gases after the combustion process is completed. The flue leading to the chimney is provided with a damper 3, so that the intensity of the draft can be regulated.

A boiler 4, which is a closed metallic vessel filled to about two-thirds of its volume with water. The heat developed by burning the fuel in the furnace is utilized in converting the water contained in the boiler into steam. The boiler 4 is arranged with a water column 5 to show the water level, with a safety valve 6 to prevent the pressure from rising too high, and with a gage 7 to indicate the steam pressure.

Boiler Setting.—The function of a setting is to provide corrects paces for the furnace, combustion chamber and ash pit, to support the boiler shell, to prevent air from entering the furnace above the fuel bed, and to decrease the heat radiation to a minimum.

The feed pump 8 supplies the boiler with water through the feed pipe 9.

The steam lines 10 and 11 convey steam from the boiler to the engine and to the steam end of the pump respectively.

In the engine the energy of the steam is expended in doing work. The steam enters the engine cylinder 12 through the valve 13 and pushes on the piston 14. The sliding motion of the piston, which is transmitted to the piston rod 15, is changed into rotary motion at the shaft 16 by means of a connecting rod 17 and crank 18.

The exhaust pipe 19 conveys the used steam to the atmosphere, condenser or to some use where its heat is abstracted, converting the steam back into water.

Classification of Boilers.—Boilers are divided into fire-tube and water-tube types. In the fire-tube the hot gases developed by the combustion of the fuel pass through the tubes, while in the water-tube boilers these gases pass around the tubes. Either type may be constructed as a vertical or as a horizontal boiler depending on whether the axis of the shell is vertical or horizontal.

The fire-tube boiler may be externally or internally fired. In the externally fired boiler the furnace is in the setting entirely outside of the boiler shell, while in the internally fired types the furnace is in the boiler shell, no brick setting being necessary.

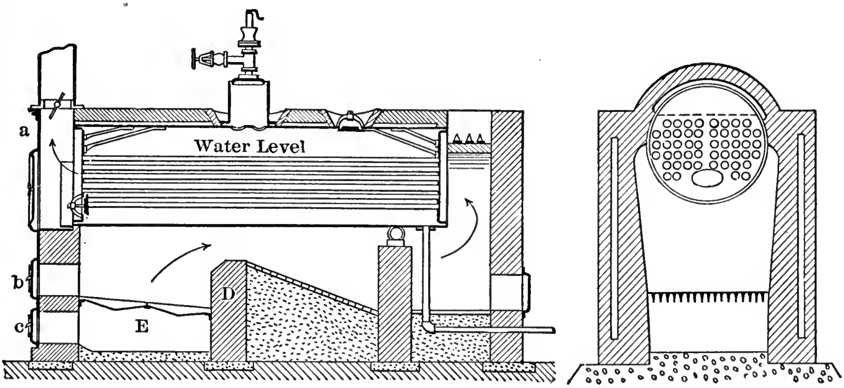


Fig. 4.

For stationary work the externally fired boiler is most common, while the internally fired types are always used for locomotive

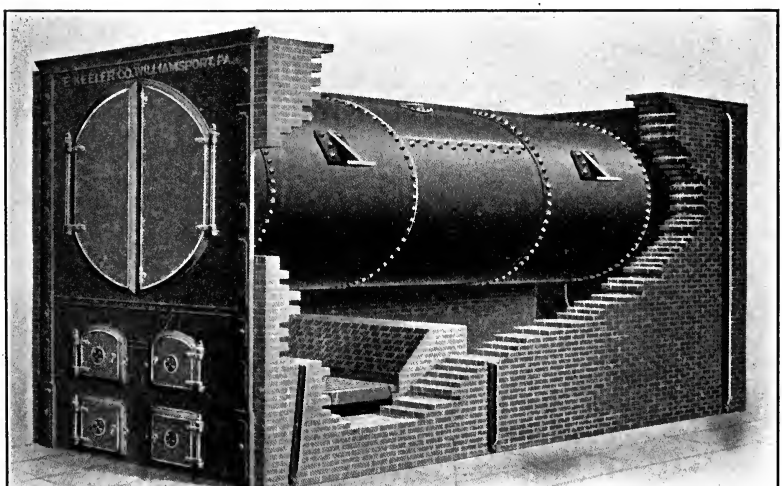


Fig. 5.

and traction engine purposes and generally for marine use. Vertical fire-tube boilers are usually internally fired.

Return Tubular Boiler.—Boilers of this type are most commonly used in this country. The general appearance of a boiler of this type is shown in Figs. 4 and 5. Fig. 6 illustrates the details of the setting.

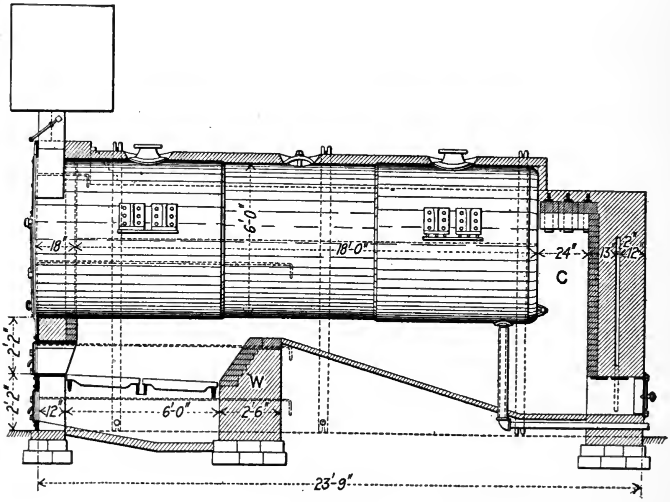


FIG. 6.

These boilers as seen from the cuts consist of a cylindrical shell closed at the end by two flat heads, and of numerous small

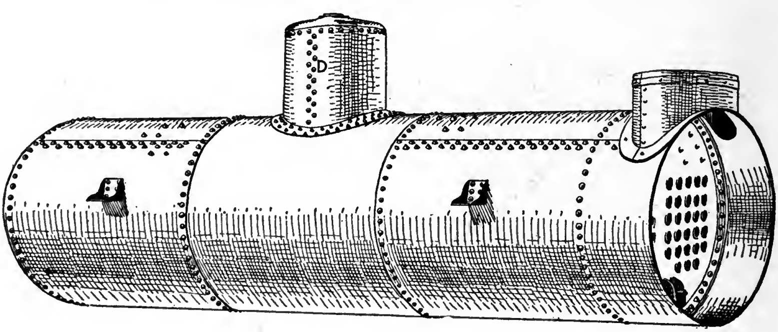


FIG. 7.

tubes which extend the whole length of the shell. Two-thirds of the volume of the shell is filled with water, the remaining part being left for the disengagement of the steam from the water,

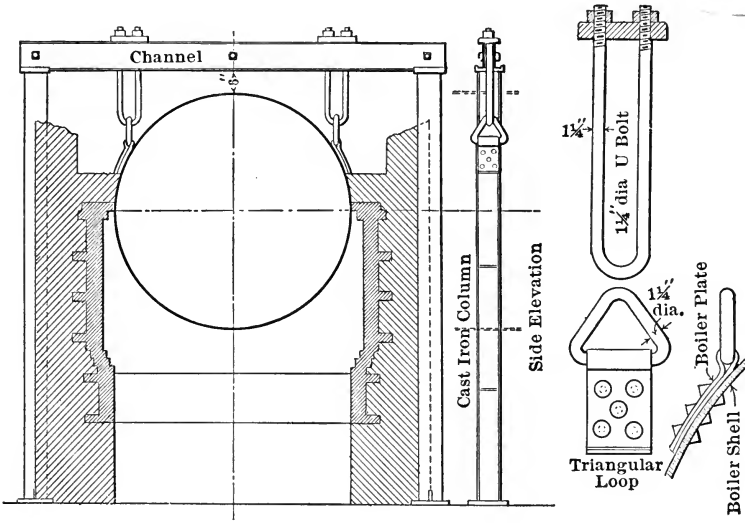

Channel
6"
Cast Iron Column
Side Elevation
1¼"
1¼"dia U Bolt
1¼"
dia.
Triangular
Loop
Boiler Plate
Boiler Shell

FIG. 8.

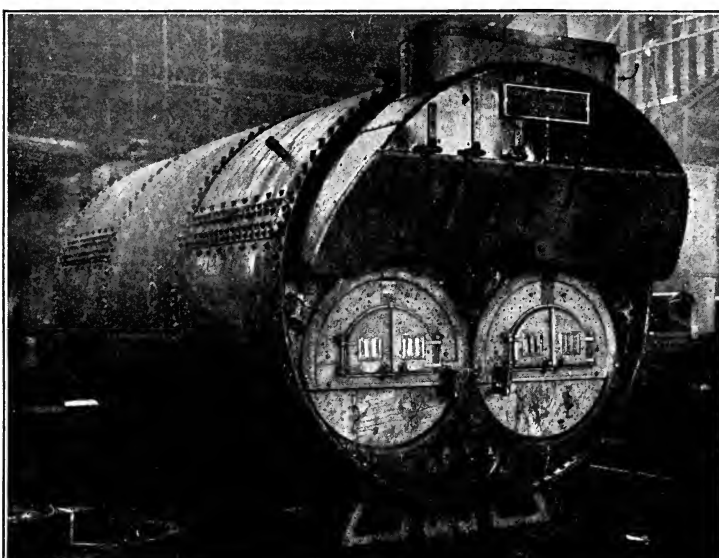


FIG. 9.

and called the steam space. Sometimes, as shown in Fig. 7, a steam dome D is provided to increase the volume of the steam space. The coal burns upon the grates which as shown in Fig. 6, rest upon the bridge wall W and upon the front of the setting. The gases pass from the furnace under and along the boiler shell to the back connection or combustion chamber C, and from there to the front through the tubes and up the uptake to the breeching or flue which leads to the chimney.

Boilers of this type are usually set in brick settings. The boiler may be supported by brackets, as shown in Fig. 5, the front ones resting directly on the side walls, while the back

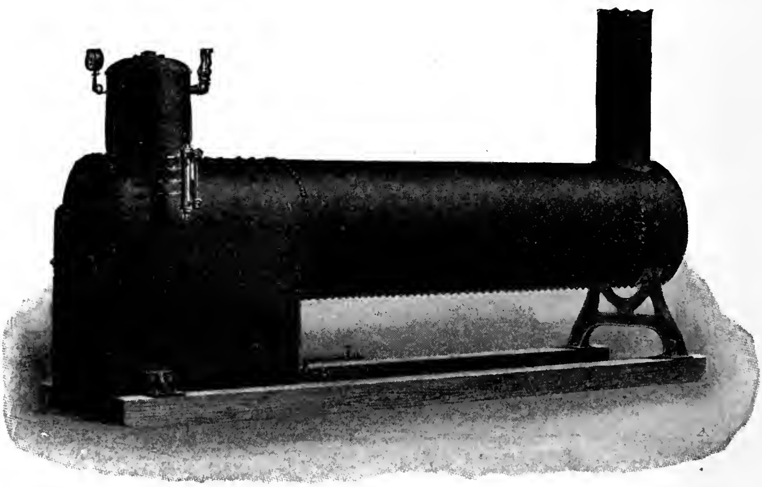


Fig. 10.

brackets are placed on rollers which in turn rest on horizontal plates, this method allowing the back of the boiler to move as the shell expands. A better method is to support the boiler independent of the setting on steel framework as shown in Fig. 8. The upper portion of the boiler shell should be covered so that the hot gases will not come in contact with the shell above the water line.

Internally Fired Boilers.—While the externally fired boiler is most commonly used, the internally fired type shown in Fig. 9 is also used to some extent. In these boilers the fire does not come in contact with the boiler shell, and this permits the construction of larger boilers and the carrying of greater pressures on account of the allowable greater thickness of shell.

The locomotive type of boiler shown in Fig. 10 is a special

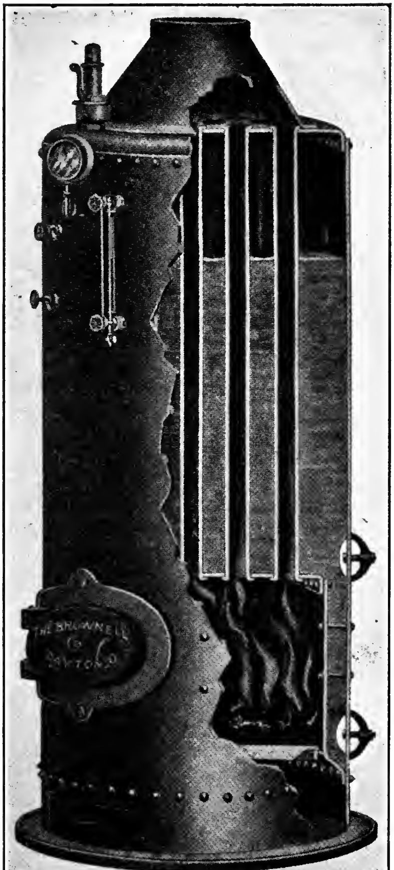


FIG. 11.

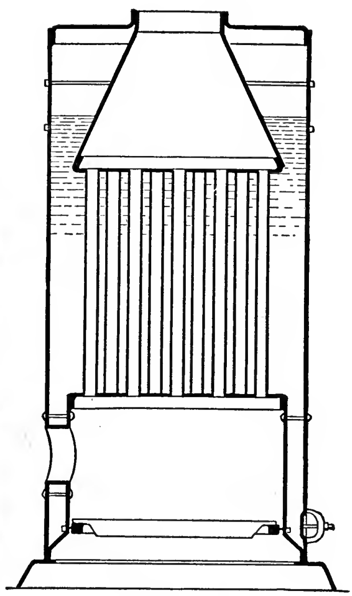


FIG. 12.

type of the internally fired boilers. This type of boiler is sometimes used for stationary purposes. It has no permanent foundation.

Vertical Fire-tube Boilers.—Two forms of vertical boilers are

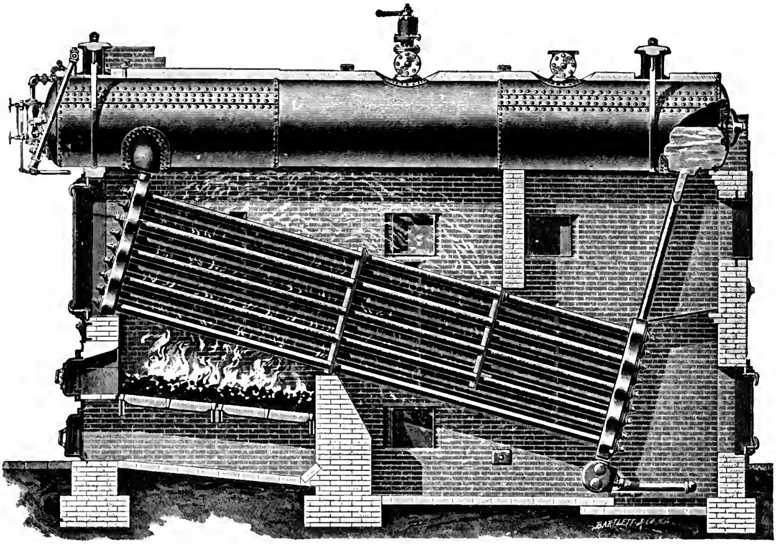


Fig. 13.

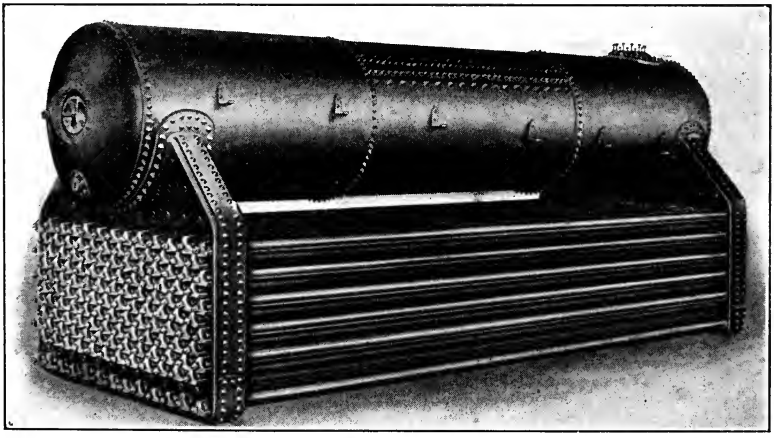


Fig. 14.

shown in Figs. 11 and 12. In the form shown in Fig. 11 the tops of the tubes are above the water line and may become overheated when the boiler is forced. To prevent injury from this cause, some forms of vertical boilers are constructed as shown in Fig. 12, the tops of the tubes being ended in a submerged tube sheet which is kept below the water line.

The essential parts of all forms of vertical boilers are a cylindrical shell with a firebox and ash pit in the lower end. The tubes lead directly from the furnace to the upper head of the shell. The hot gases from the furnace pass through the tubes

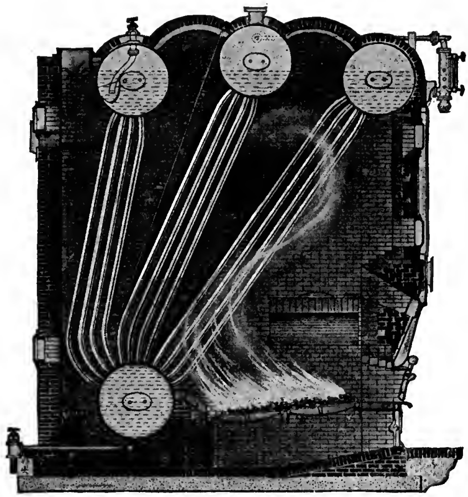


Fig. 15.

and out of the stack. The firebox is surrounded with water as in the case of the locomotive boiler.

Vertical boilers occupy little floor space and require no setting or foundation. They can also be used as portable boilers.

Water Tube Boilers.—Water tube boilers are used in large power plants on account of their adaptability to higher pressures and larger sizes, decreased danger from serious explosions, greater space economy, and rapidity of steam generation. For small power plants the fire tube boiler is usually more suitable on account of its lower first cost. Also in a fire tube boiler if a tube should break, the boiler can be repaired by plugging without interrupting service, which is not the case with most types of water tube boilers. As far as economy is concerned, numerous tests show that either type when properly designed and operated will give the same economy.

There are many different types of water tube boilers on the market, but the essential parts of all are tubes filled with water and one or more drums for the disengagement of the steam from the water.

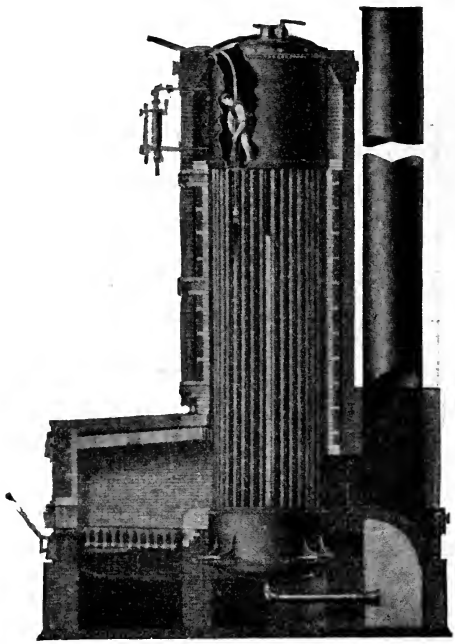


Fig. 16.

Water tube boilers are commonly divided into three classes: In one class the tubes are fastened into several sets of headers, which are connected to a common drum. The Babcock and Wilcox boiler shown in Fig. 13 represents this class. The hot gases from the furnace are directed by means of fire brick baffle plates and by the bridge-wall to pass across the tubes three times on the way to the uptake at the back of the boiler.

In another type the Heine, shown in Fig. 14, all the tubes end in one common header at each end. In this type the baffle plates are arranged horizontally so that the hot gases pass along the tubes several times on the way to the breeching.

Under the third type are included water tube boilers which have more than one drum connected by tubes. The Stirling and Wickes shown in Figs. 15 and 16 are examples of these types.

Grates for Boiler Furnaces.—Grates are formed of cast-iron

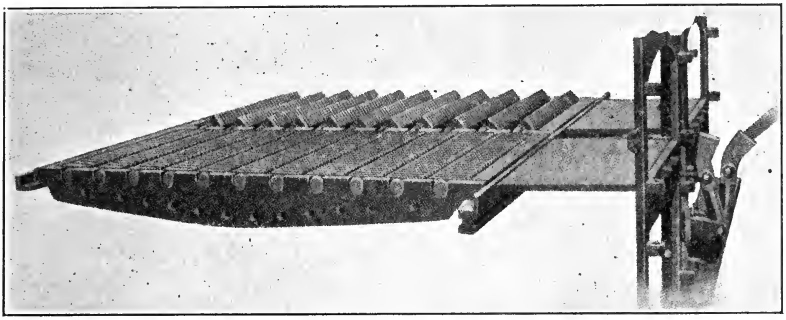


Fig. 18.

bars. Several forms of grate bars are illustrated in Figs. 17 and 18. Plain grates are best adapted for caking coals and are usually provided with iron bars cast in pairs and lugs at the side. The Tupper type of grate is more suitable for the burning of hard coal which does not cake. The grates of a boiler furnace can

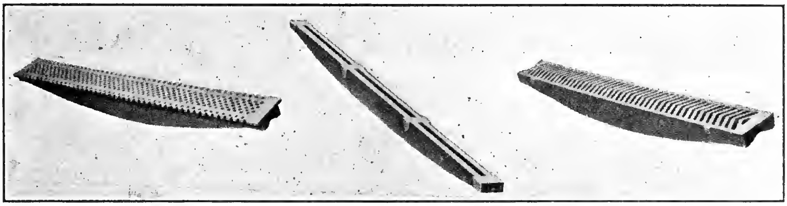


Fig. 17.

be easily interchanged to suit the fuel burned. For most economical results some form of rocking and dumping grate, as shown in Fig. 18, should be used.

Piping for Boilers.—Pipes used for carrying steam are made of wrought iron or steel. Wrought iron pipe is superior to steel

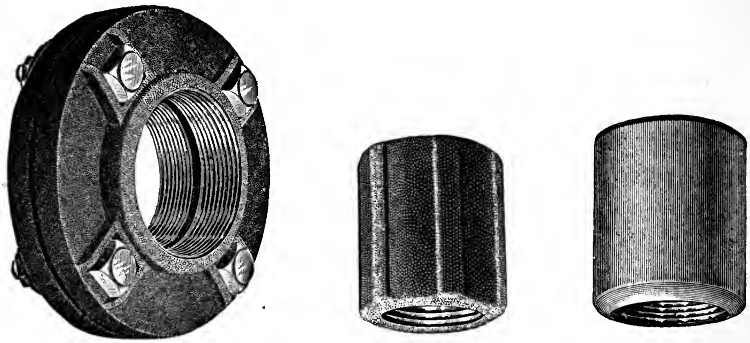


Fig. 19.

Fig. 20.

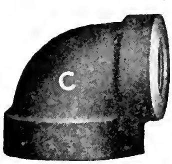


Fig. 21.

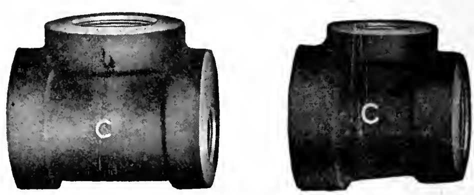


Fig. 22.

Fig. 23.

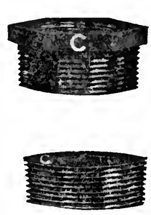


Fig. 24.

Fig. 25.

pipe as far as durability is concerned, but is more expensive and more difficult to secure. Sizes of steam pipe are named by the inside diameter, while boiler tubes go by the outside diameter. Standard steam pipe is made in sizes of 1/8, 1/4, 3/8, 1/2, 3/4, 1, 1 1/4, 1 1/2, 2, 2 1/2, 3, 3 1/2, 4, 4 1/2, 5, 6, 7, 8, 9, 10, 11 and 12 in. Sizes above 12 in. are named by the outside diameter.

The various grades of pipe are merchant, standard, extra heavy and double extra heavy. Merchant pipe is somewhat lighter than standard pipe and its manufacture is being discontinued. Extra heavy and double extra heavy have the same outside diameters as standard pipe, but the inside diameters are smaller, due to the greater thickness of the pipe.

Steam pipe lines should always be laid with a gradual inclination downward, so as to allow the condensation that occurs to flow in the direction in which steam is moving. If this is not done water may accumulate, will be picked up by the steam and may cause much damage by water hammer.

Pipe Fittings.—Figure 19 illustrates several forms of pipe unions, which are used for uniting two lengths of pipe.

The elbow or ell shown in Fig. 20 is employed for connecting two pipes of the same size and at right angles to each other. If the pipes are of different diameters a reducing ell as shown in Fig. 21 should be used.

Fig. 26.

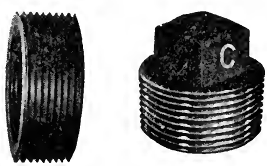


Fig. 27.

The tee shown in Fig. 22 is used for making a branch at right angles to a pipe line.

The cross shown in Fig. 23 is used when two branches must be made in opposite directions.

In order to reduce the size of a pipe line a bushing, Fig. 24, or a reducer, Fig. 25, can be used.

To close the end of a pipe a cap, Fig. 26, is used, while the plug shown in Fig. 27 is used to close a pipe threaded on the inside or a fitting.

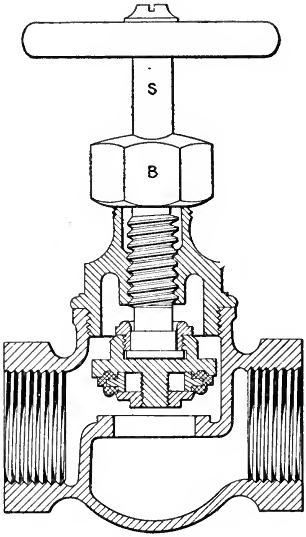


Fig. 28.

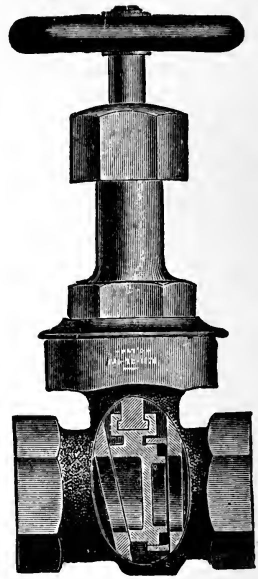


Fig. 29.

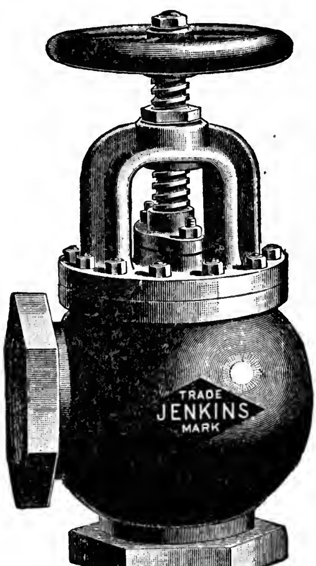


Fig. 30.

Valves.—The function of a valve is to control and regulate the flow of water, steam or gas in a pipe. In the globe valve in Fig. 28 the fluid usually enters at the right, passes under the valve and out at the left.

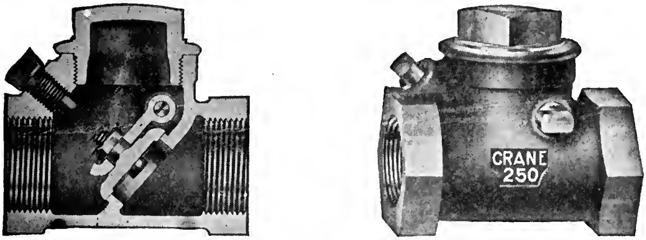


Fig. 31.

This method of installation places the pressure of the steam, or other fluid, against the disc in such a way that it tends to open the valve. The advantages claimed for this method are:

1. When the valve is closed the stems may be packed without cutting the steam pressure off the entire line.

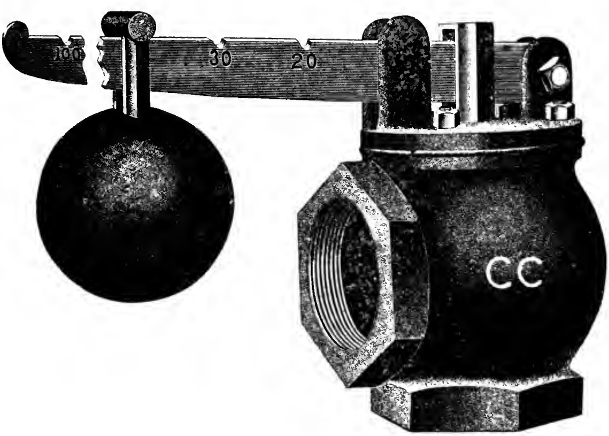


Fig. 32.

2. The adjustment of the opening can be made more accurately against the steam pressure than with it.

3. The flow of steam tends to keep the valve seat free from scale and other dirt.

Those who favor the other method claim, as the principal advantage, that the pressure of the steam, when the valve is closed, tends to keep it in that position and that there is much less likelihood of the valve leaking. Both methods will be found in use, but it is probable that a large majority of the installations will be found to be in accordance with the first method.

A gate valve is shown in Fig. 29. This form of valve gives a straight passage through the valve, and is preferable for most purposes to the globe valve.

Figure 30 illustrates an angle valve which takes the place of an ordinary valve and ell.

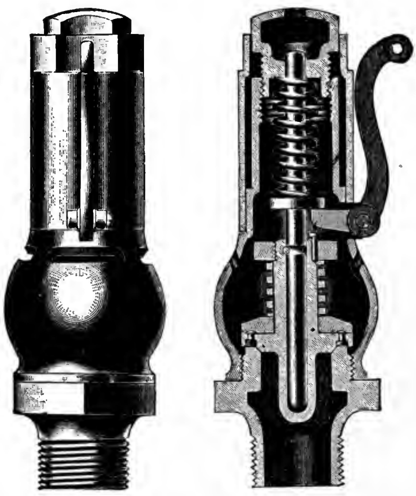


Fig. 33.

The function of a check valve illustrated in Fig. 31 is to allow water or steam to pass in one direction but not in the other.

A boiler feed line should always be provided with a check valve and also with some form of globe or gate valve to enable the operator to examine and repair the check valve.

Safety Valves.—The function of a safety valve is to prevent the steam pressure from rising to a dangerous point. The two common forms of safety valves are the lever safety valve and the spring or pop safety valve.

The lever safety valve shown in Fig. 32 consists of a valve disc which is held down on the valve seat by means of a weight acting through a lever, the steam pressing against the bottom of the disc. The lever is pivoted at one end to the valve casing and is marked at a number of points with the pressure at which the

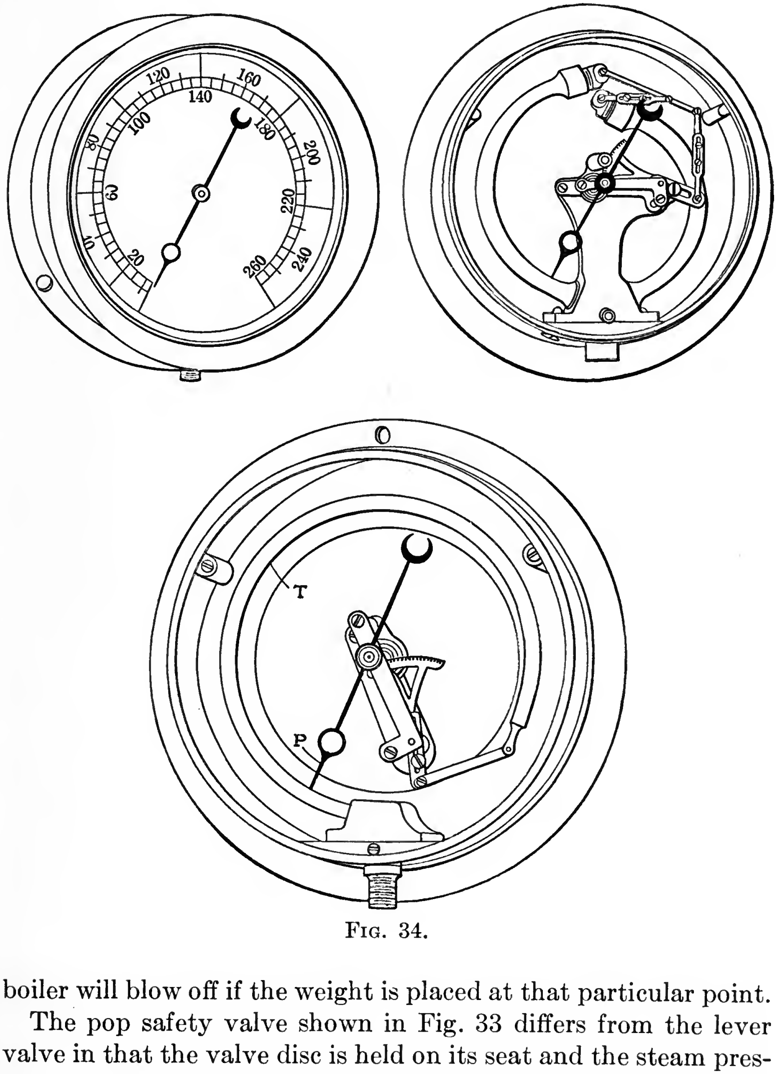


Fig. 34.

boiler will blow off if the weight is placed at that particular point.

The pop safety valve shown in Fig. 33 differs from the lever valve in that the valve disc is held on its seat and the steam pressure is resisted by a spring in place of a weight and lever. Pop safety valves can be adjusted to blow off at various pressures by tightening or loosening the spring pressure on the valve disc.

Steam Gages.—A steam gage indicates the pressure of the

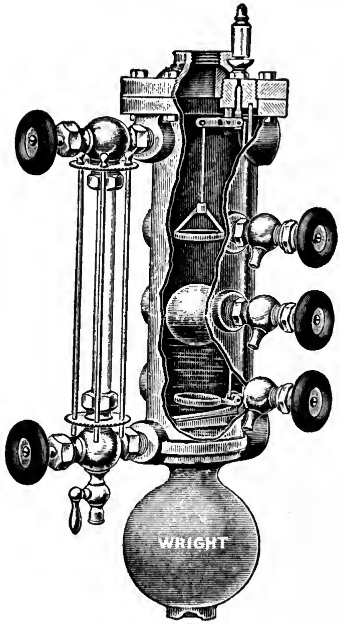


Fig. 35.

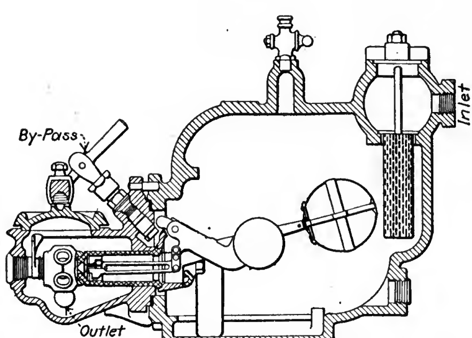


Fig. 36.

steam in a boiler. The most common form, shown in Fig. 34 consists of a curved spring hollow tube closed at one end and filled with some liquid. One end of the tube is free, while the other is fastened to the fitting which is secured into the space where the pressure is to be measured. Pressure applied to the inside of the tube causes the free end to move. This motion is communicated by means of levers and small gears to the needle which moves over a graduated dial face, and records the pressure directly in pounds per square inch.

Water Glass and Gage Cocks.—The height of the water level in a boiler is indicated by a water glass, one end of which is connected to the steam space and the other end to the water space in the boiler. All boilers should also be provided with three gage cocks, one of which is set at the desired water level, one above and one below. These are more reliable than the water glass and should be used for checking the glass.

FIG. 37.

Water Column.—The steam gage, water glass and gage cocks are usually fastened to a casting called a water column. One form of water column is shown in Fig. 35, this also being fitted with a float and whistle to notify the operator should the water in the boiler become too low or too high. A fireman who takes proper care of the boilers in his charge will never allow the water to be at a height as will necessitate audible warning.

Steam Traps.—The object of a steam trap is to drain the water from pipe lines without allowing the steam to escape. Two forms of steam traps are shown in Figs. 36 and 37, the valve being controlled by a float when the water in the trap rises to a sufficient height.

Feed Pumps and Injectors.—Water is forced into steam boilers by pumps or injectors. A pump will handle water at any temperature, while an injector can be used only when the water

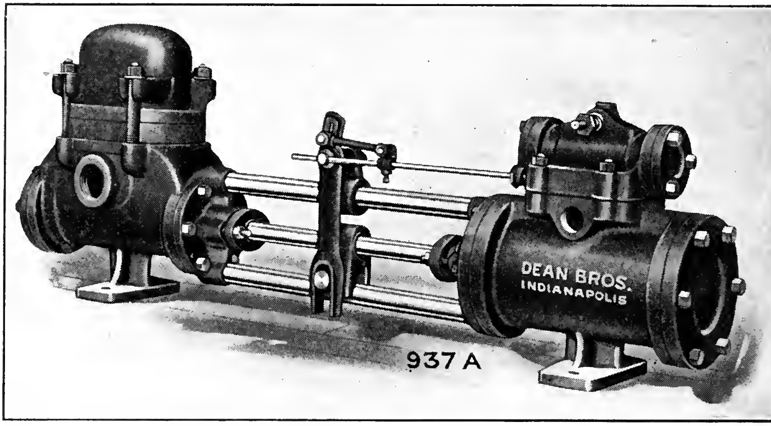


Fig. 38.

is cold. The injector is not as wasteful of steam as a pump and for feeding cold water to a boiler has the additional advantage, that it heats the water while feeding it to the boiler.

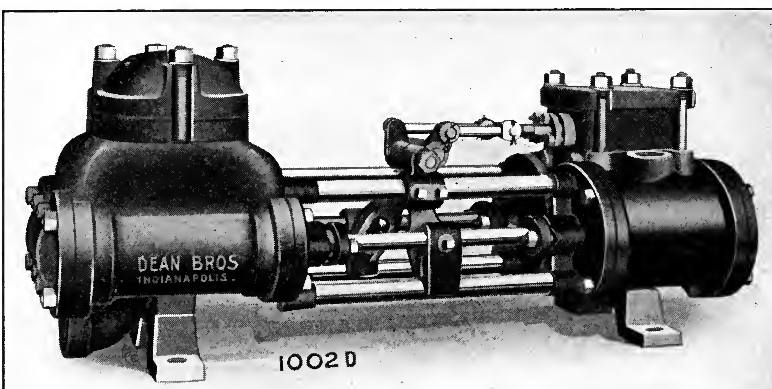


Fig. 39.

Feed pumps may be driven from the cross-head of an engine as is often the case on traction engines. Such pumps are very

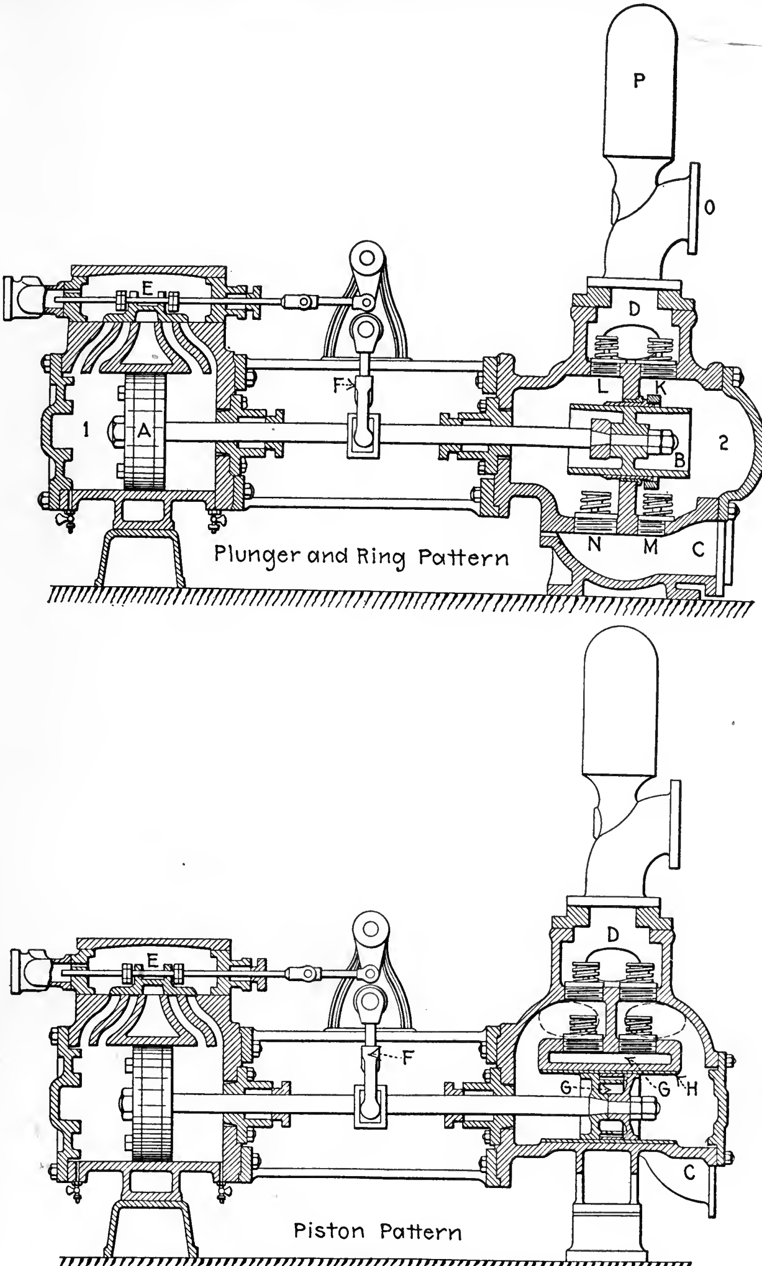

P
O
E
D
F
L
K
1
A
2
B
N
M
C
Plunger and Ring Pattern
E
D
F
G
G
H
C
Piston Pattern

FIG. 40.

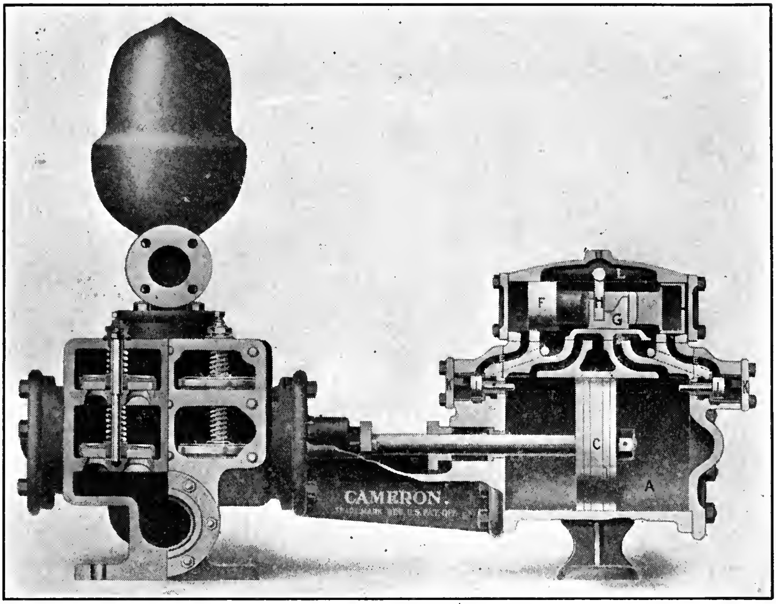


Fig. 41.

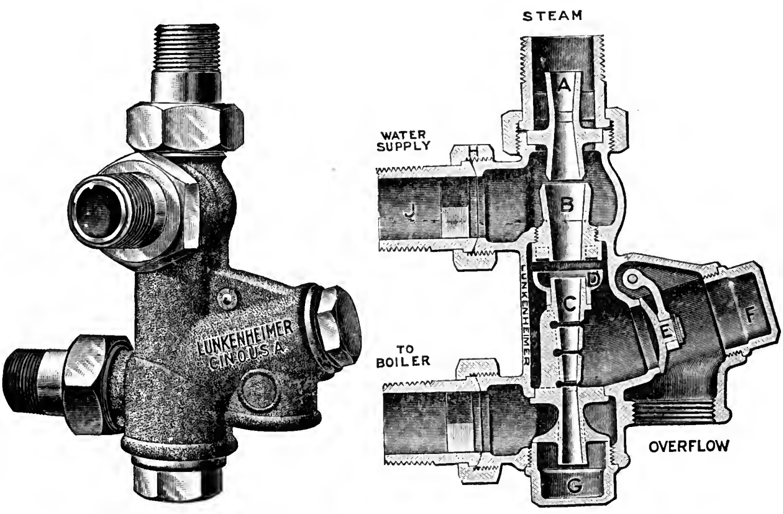


Fig. 42.—Injector.

simple, but can only supply water to the boiler when the engine is in operation.

Direct-acting steam pumps, driven by their own steam cylinders, are most commonly used for feeding boilers, as they can be operated independently of the main engine and their speed can be regulated to suit the feed water demand of the boilers.

If a direct-acting pump consists of one steam cylinder and one water cylinder, as shown in Fig. 38, it is called a single pump. Duplex pumps have two steam cylinders and two water cylinders, as shown in Fig. 39, the steam valve of one being operated from the piston rod of the other.

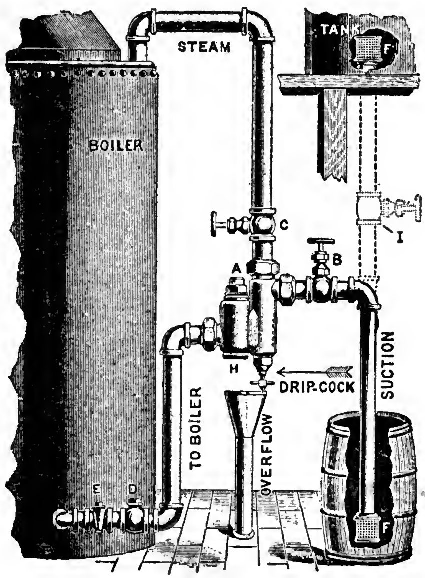


FIG. 43.

The details of construction of two forms of direct-acting pumps are shown in Figs. 40 and 41.

In the pump shown in Fig. 40, 1 is the steam cylinder and 2 is the water cylinder. The valve E is moved by the vibrating arm F and admits steam into the cylinder 1. If steam is admitted at the left of the piston A, the piston will be moved to the right, pushing the plunger B, driving the water through the water valve K, and into the feed line at O. While the plunger is moving to the right, a partial vacuum is formed at its left, which opens the valve N and drains the water from the supply at C. When the plunger B reaches the extreme position to the right, the vibrating arm F moves the valve E to the left, admitting steam which pushes the piston and plunger to the left, driving the water through the valve L and taking a new supply through M. The function of the air chamber P is to secure a steady flow of water through the discharge O and to prevent shock in the piping.

The pump shown in Fig. 41 differs from the one just described in that the steam valve G is operated by the steam in the steam chest and not by a vibrating arm outside of the cylinder. The piston C is driven by steam admitted under the slide valve G, this valve being moved by a plunger F. This plunger F is hollow at the ends and the space between it and the head of the steam chest is filled with steam. Thus the plunger remains motionless until the piston C strikes one of the valves I exhausting the steam through the part E at one end. The water end is similar to that of the pump in Fig. 40.

Injectors are used very commonly for the feeding of portable and of small stationary boilers. In larger plants injectors are sometimes used in conjunction with pumps as an auxiliary method for feeding boilers.

The general construction of an injector is illustrated in Fig. 42. Steam from the boiler enters the injector nozzle at A, flows through the combining tube BC and out to the atmosphere through the check valve E and overflow F. The steam in expanding through the nozzle A attains considerable velocity, and forms sufficient vacuum to cause the water to rise to the injector. The steam jet at a high velocity coming in contact with the water is condensed, gives up its heat to the water and imparts a momentum which is great enough to force the water into the boiler against a steam pressure equal to or greater than that of the steam entering the injector.

As soon as a vacuum is established in the injector and the water begins to be delivered to the boiler the check valve E at the overflow closes. Should the flow of feed water to the boiler be interrupted, due to air leaking into the injector or to some other cause, the overflow will open and the steam will escape to the atmosphere.

The method of connecting an injector to a vertical boiler is illustrated in Fig. 43. To facilitate the taking down of an injector for inspection and repairs it should be connected up with unions.

Due to the fact that the vacuum in an injector is broken as the temperature of the water increases, injectors can only work when the feed water is 150° F. or cooler.

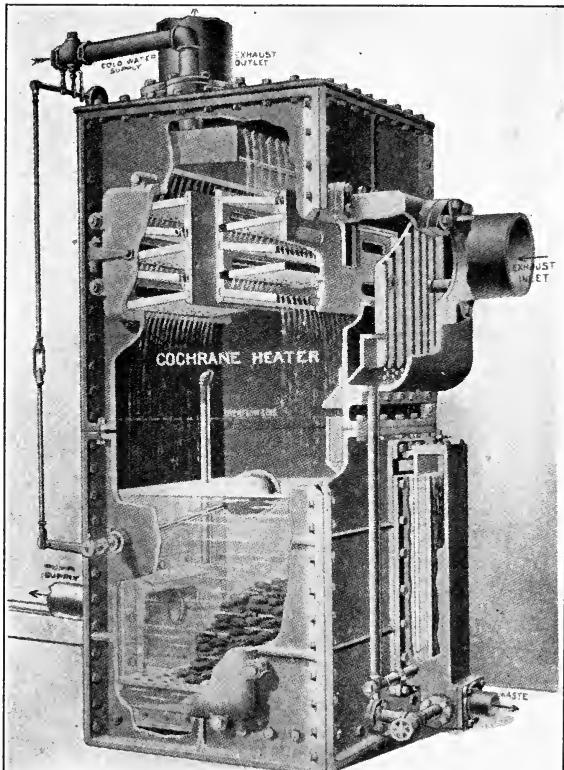


FIG. 44.

Feed-water Heaters.—If cold water is fed to a boiler, the temperature at the place where the water is discharged will be different from that in the other parts of the boiler, and strains due to unequal expansion and contraction will be set up which will decrease the life of the boiler, besides impairing the tightness of the setting. With hot feed water strains due to unequal expansion are prevented. Also for every 10° increase in the temperature of the feed water a gain of about 1 per cent. in the

FIG. 45.

fuel economy can be expected. This also means that the capacity of a boiler plant can be increased by the installation of some apparatus, outside of the boiler, for the heating of feed water.

This increase in capacity can usually be accomplished at much less cost than by increasing the size of the boiler. Heating the feed water outside of the boiler serves also to purify the water before it enters the boiler.

Feed-water can be heated by live steam, by exhaust steam, or by the waste chimney gases.

The heating of feed water by live steam is not recommended, as the advantage of this method lies mainly in the amelioration of unequal expansion.

Feed-water heaters which utilize the heat of exhaust steam from engines and pumps are most commonly used. Such heaters may be constructed so that the exhaust steam and water come in direct contact and the steam gives up its heat by condensation Such heaters are called open feed-water heaters. One form of open feed-water heater is shown in Fig. 44. The water passes over trays upon which the impurities thrown out of the water by heating it are deposited, and can be easily removed.

If it is desired to prevent the steam and water from coming in contact with each other, some form of closed heater, as shown in Fig. 45, should be used. In the case of closed heaters the steam on one side of a tube, heats the water on the other. Such heaters may be constructed so that either the steam or the water flows through the tubes.

Chimneys and Artificial Draft-producing Systems.—A chimney or stack is used to carry off the obnoxious gases formed during the process of combustion at such an elevation as will render them unobjectionable. Another very important function performed by a chimney is to produce a draft which will cause fresh air, carrying oxygen, to pass through the fuel bed, producing continuous combustion.

The draft produced by a chimney is due to the fact that the hot gases inside the chimney are lighter than the outside cold air. In the boiler plant the cold air is heated in passing through the fuel bed, rises through the chimney and is replaced by cold air entering under the grate.

The amount of draft produced by a chimney depends on its height, the taller the chimney, the greater is the draft produced, since the difference in weight between the column of the inside and that of the air outside increases as the height of the chimney.

The intensity of chimney draft is measured in inches of water, which means that the draft is strong enough to support a column of water of the height given. The draft produced by chimneys is usually 1/2 to 3/4 in. of water.

Chimneys are made of brick or concrete or steel. For small plants steel stacks are more desirable. A brick chimney unless carefully constructed may allow large quantities of air to leak in which will interfere with the intensity of the draft. Steel stacks are also cheaper. Brick chimneys as usually constructed have two walls, with an air space between them. The inside wall should be lined with fire brick.

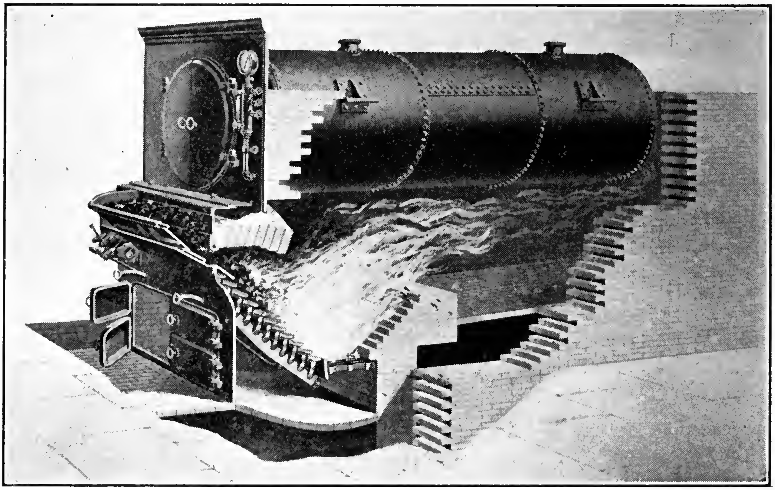


Fig. 46.

Draft produced by chimneys is called natural draft.

In some cases the draft produced by chimneys is insufficient and some artificial method has to be used.

Artificial draft may be produced by steam jets, as is common in locomotive and traction-engine practice. This system is uneconomical, and is only used in connection with land boilers to reduce the clinkering of certain grades of coal.

Firing.—To the average person firing consists merely of opening the furnace door and throwing fuel on the grate. It has been found that some system of firing must be adopted in order to produce economical combustion of coal.

The system to be adopted depends mainly on the kind of fuel.

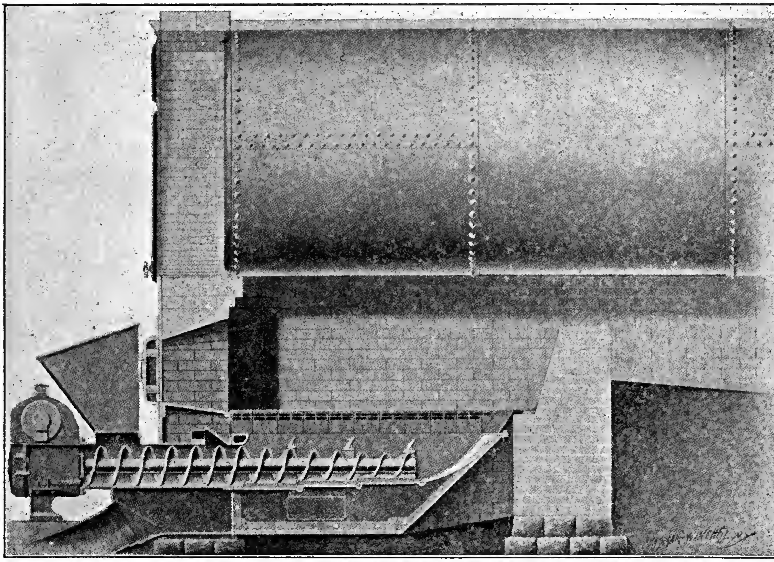


FIG. 47.

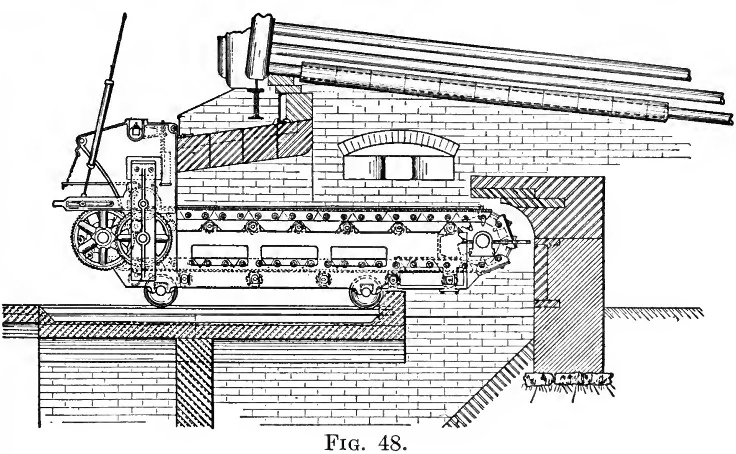


FIG. 48.

The spreading system consists of distributing a small charge of coal in a thin layer over the entire grate. This system will give satisfactory results with anthracite coal and with some bituminous coals. With this method, if the fuel is fed in large quantities and at long intervals, incomplete combustion will result.

The alternate method consists of covering first one side of the grate with fresh fuel and then the other. The volatile gases that pass off from the fresh fuel on one side of the grate are burned with the hot air coming from the bright side of the fire. This system is best applied to a boiler with a broad furnace.

The coking method is best adapted for smoky and for the caking varieties of bituminous coal. In this method the coal is put in the front part of the furnace, and allowed to remain there until the volatile gases are driven off; it is then pushed back and spread over the hot part of the furnace, and a new charge is thrown in the front.

Either one of the three systems of firing explained will produce good results, if properly carried out and if the fire is kept bright and clean. Smoke indicates incomplete combustion and with bituminous coal occurs if the volatile gases are allowed to pass off unburned. If the boiler is set too close to the grate, the volatile gases driven off from the coal are brought in contact with the comparatively cool surfaces of the boiler shell or tubes and smoke is produced.

Mechanical Stokers.—In all cases the best results can be obtained by firing coal frequently and in small quantities. With mechanical stokers this can be accomplished and one man can attend to a large number of furnaces.

Mechanical stokers can be arranged to feed or spread the coal over the fire or to push the coal from below the fire. Both methods are illustrated in Figs. 46 and 47, respectively. Another type of stoker consists of an endless chain grate driven by an engine. This type of stoker, called the chain-grate stoker is illustrated in Fig. 48.

With mechanical stokers inferior fuels can be burned without smoke, but for small power plants they are not used on account of the initial high cost, large repair bills and cost of power for operating the stoker mechanism.

Rating of Boilers.—Boilers are usually rated in horse-power. The term horse-power in this connection is only a matter of convenience in rating boilers, and does not mean the rate of doing work, but is an arbitrary unit applying to the evaporation of a definite amount of water. The American Society of Mechanical Engineers has recommended that one boiler horse-power should mean the evaporation of 30 lb. of water per hour at 100° F. into steam at 70 lb. gage. This is equivalent to the evaporation of 34 1/2 lb. of water from feed water at 212° F. into steam at 212° F.

Boiler manufacturers often rate boilers in square feet of heating surface. It has been found that each square foot of boiler heating surface can evaporate economically 3 to 3.4 lb. of water, so that a boiler horse-power can be produced by 10 to 12 sq. ft. of boiler heating surface.

Management of Boilers.—Before a boiler is started for the first time, its interior should be carefully cleaned, care being taken that no oily waste or foreign material is left inside of the boiler. The various manholes and handholes are then closed and the boiler is filled to about two-thirds of its volume with water. The fire is started with wood, oily waste or other rapidly burning materials, keeping the damper and ash-pit door open. The fuel bed is then built up slowly.

While getting up the steam pressure, the gage glass should be blown out to see that it is not choked, the gage cocks should be tried and all auxiliaries such as pumps, injectors, pressure gages, piping, etc., carefully examined. The safety valve should be carefully examined and tried out before cutting the boiler into service.

When cutting a boiler into service with other boilers, its pressure should be the same as that of the other boilers. Steam valves should be opened and closed very slowly in order to prevent water hammer and stresses from rapid temperature changes.

During the operation of a steam boiler the safety valve should be kept in perfect condition and tried daily by allowing the pressure to rise gradually until the valve begins to simmer. Each boiler should have its own safety valve and no stop-valve should be placed under any condition between it and the boiler. The steam gage should be calibrated from time to time with standard gage or still better by some form of dead-weight tester. It is best not to depend on the water gage glass and the gage cocks should be used for checking the water level of a boiler.

In case of low water do not turn on the feed, but shut the damper, cover the fuel bed with ashes, or if that is not available with green coal. In case of low water the safety valve should not be lifted until the boiler has cooled down, or an explosion may occur.

A boiler should be cleaned often and kept free from scale. If clean water is used a boiler may be run several months without fear of serious scale formation, but in most places boilers should be cleaned at least once each month. When preparing to clean a boiler allow it to cool down, and the water to remain in the shell until ready to commence cleaning.

In emergencies split tubes may be plugged with iron plugs without throwing the boiler out of service. Also if a tube becomes leaky in the tube sheet this can be remedied by inserting a tapering sleeve slightly larger than the inside diameter of the tube.

CHAPTER V

STATIONARY STEAM ENGINES

Description of the Steam Engine.—A steam engine is a motor which utilizes the energy of steam. It consists essentially of a piston and cylinder with valves to admit and exhaust steam, a governor for regulating the speed, some lubricating system for reducing friction, and stuffing boxes for preventing steam leakage.

In its simplest form, the steam hammer, the steam acting on the piston lifts weights against the force of gravity.

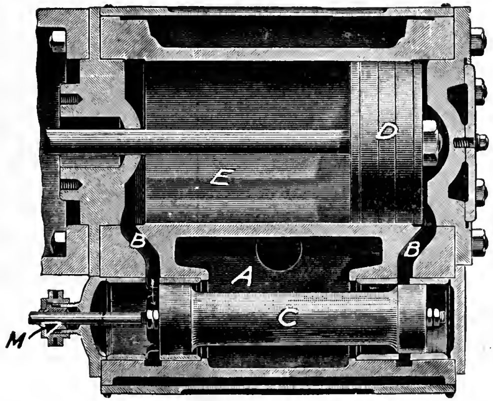


Fig. 49.

In the steam engine working as a motor continuous rotary motion of a shaft is essential. This is accomplished by the interposition of a mechanism consisting of a connecting rod and crank, which changes the to-and-fro or reciprocating motion of the piston into mechanical rotation at the shaft. A steam engine in which the reciprocating motion of the piston is changed into rotary motion at the crank is called a reciprocating steam engine to differentiate this form of motor from the steam turbine to be described later.

The various parts of a steam engine are illustrated in Figs. 49 and 50.

Steam from the boiler at high pressure enters the steam chest A, Fig. 49, and is admitted through the ports BB alternately to either end of the cylinder by the slide valve C. The same valve also releases and exhausts the steam used in pushing the piston D. E is the cylinder in which the steam is expanded. The motion of the piston D, Fig. 50, is transmitted through the piston rod F to the cross-head G, and through the connecting rod H to the crank I which is keyed to the shaft K.

The shaft is connected directly, or by means of intermediate connectors such as belts or chains, to the machines to be driven.

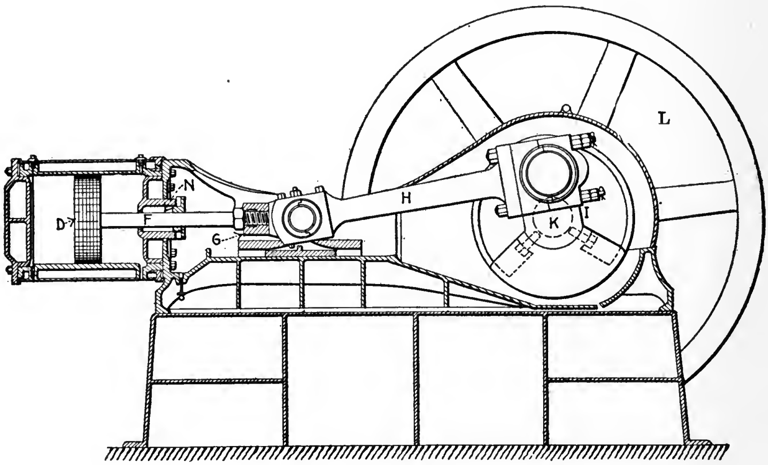


Fig. 50.

The shaft carries the flywheel L, the function of which is to make the rate of rotation as uniform as possible and to carry the engine over dead center. The dead center occurs when the crank and connecting rod are in a straight line at either end of the stroke, at which time the steam acting on the piston will not turn the crank. A flywheel is sometimes used as a driving pulley, as shown in Fig. 51.

The eccentric shown in Fig. 51 also rotates with the shaft. An eccentric is a crank of special form which imparts reciprocating motion to the valve through the eccentric rod and valve stem.

The eccentricity of the eccentric is the distance between the center of the eccentric and the center of the shaft. The travel of the valve is equal to the throw of the eccentric, or twice the eccentricity. Changing the eccentricity changes the travel of the valve.

Stuffing boxes which prevent the escape of steam around the rods are illustrated at M and N in Figs. 49 and 50.

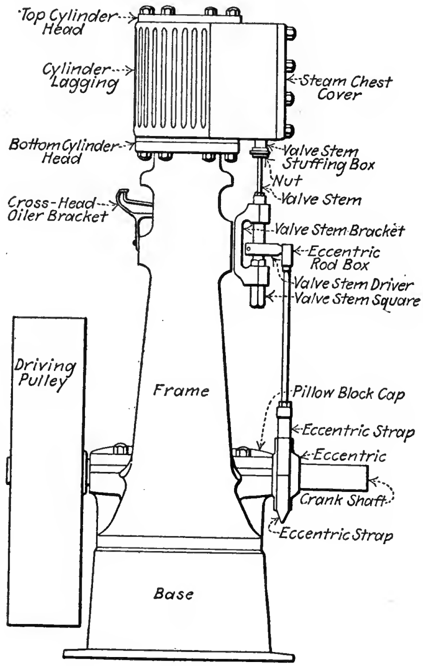


Fig. 51.

The size of a steam engine is given in terms of the cylinder diameter and length of stroke of the engine. Thus if an engine is called an 8-in. by 10-in. engine, this means that the diameter of its cylinder is 8 in. and its stroke or piston travel is 10 in.

Action of the Plain Slide Valve.—The action of the plain slide valve will now be taken up in detail, as a thorough knowledge of this type of valve will enable one to understand all other forms. Referring to Fig. 52 which shows a section of a cylinder with the slide valve in mid-position, A and B are the steam ports, which lead to the two ends of the cylinder; C is the exhaust space.

The steam ports are separated from the exhaust space by the two bridges D and E. F is the steam chest. V is a plain slide valve, commonly called a D slide valve. The amount S that the valve V overlaps the outside edge of the port, when in the middle of of its stroke, is called the steam lap. Similarly the amount by

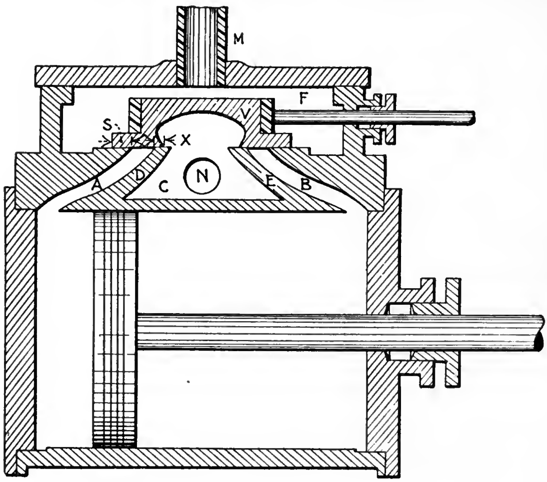


Fig. 52.

which the valve overlaps the inside edge of the port when it is in mid-position is called the exhaust lap. M and N are the steam and exhaust pipes respectively.

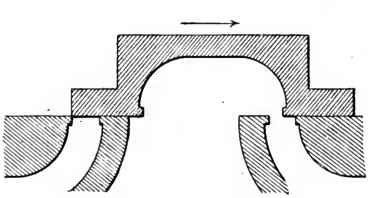


Fig. 53.

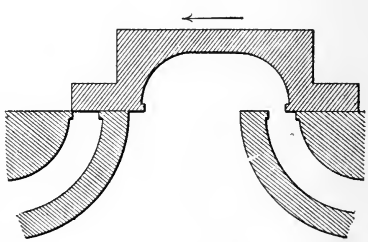


Fig. 54.

The four valve events are: admission, cut-off, release and compression. Admission is that point at which the valve is beginning to uncover the port, as shown in Fig. 53. Cut-off occurs (Fig. 54) when the valve covers the port preventing further admission of steam. This is followed by the expansion of the steam until the cylinder is communicated with the exhaust opening, at which time release as shown by Fig. 55 occurs. Compression occurs when communication between the cylinder and exhaust opening is interrupted (Fig. 56) and the steam remaining in the cylinder is slightly compressed by the piston. The valve is in the same position at cut-off as it is at admission, only it is traveling in the opposite direction. Similarly the positions of the valve are the same at release and compression.

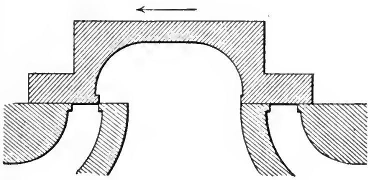


Fig. 55.

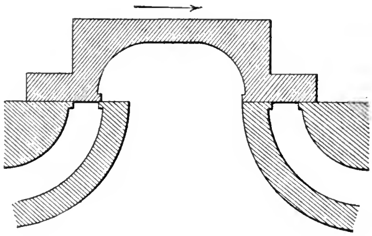


Fig. 56.

By lead is meant the amount that the port is uncovered when the engine is on either dead center. The object of lead is to supply full pressure steam to the piston as soon as it passes the dead center.

If a valve is constructed without laps as shown in Fig. 57, steam would be admitted to the cylinder at one end or the other and exhausted at the opposite end, if the valve is moved slightly

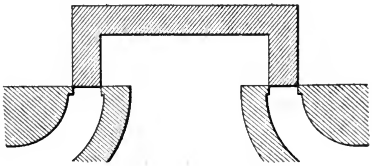


Fig. 57.

in either direction. This would mean that steam admission at one end would take place throughout the entire stroke of the piston and would be exhausted from the opposite end at the same time. It is evident that a valve without laps will have no cut-off and steam will not be used expansively. To use steam without expansion is very uneconomical and is resorted to only n direct acting steam pumps. For best economy a steam engine should be provided with a valve which cuts off at about one-third of the stroke.

Types of Steam-engine Valve Gears.—The simplest type of valve for steam engines is the single-slide valve, which controls the admission and exhaust of steam alternately to each end of the cylinder. The form shown in Fig. 49 is called a piston valve. In the position shown it admits steam to the head of the cylinder, the end farthest away from crank, and at the same time exhausts

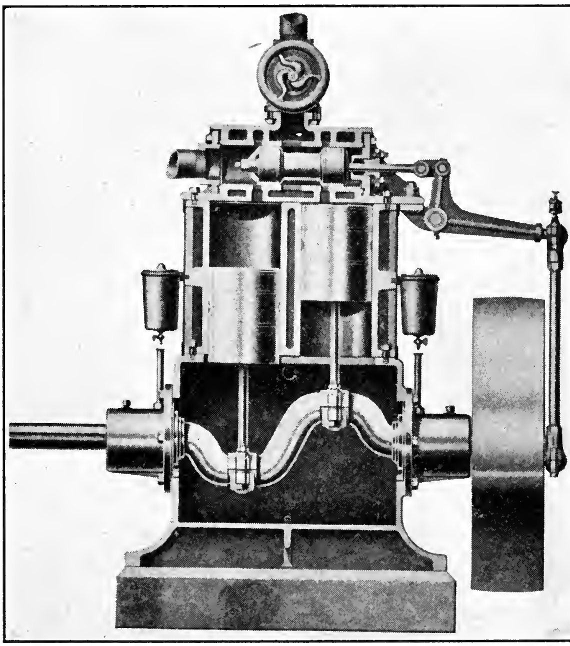


Fig. 58.

the steam from the crank end of the cylinder. An engine with a piston valve is illustrated in Fig. 58.

Still a simpler type of valve, the plain slide valve, often used on portable and on traction engines, is shown in Fig. 52. The objection to this type of valve is that it is not balanced, and, either the friction of the valve on its seat is excessive, or the valve allows steam to leak into the exhaust space. This is remedied by the piston valve shown in Fig. 49, which is perfectly balanced,

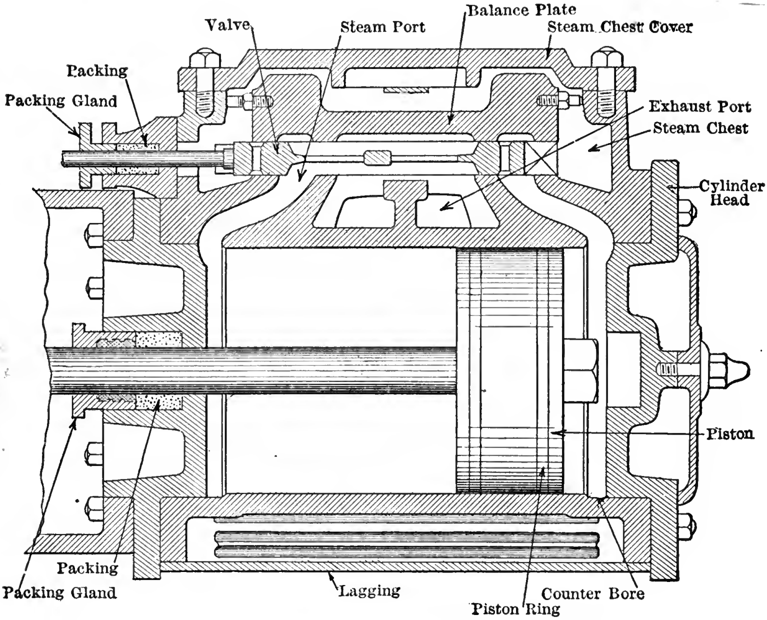

Balance Plate
Valve
Steam Port
Steam Chest Cover
Packing
Packing Gland
Exhaust Port
Steam Chest
Cylinder Head
Piston
Packing
Packing Gland
Lagging
Counter Bore
Piston Ring

FIG. 59.

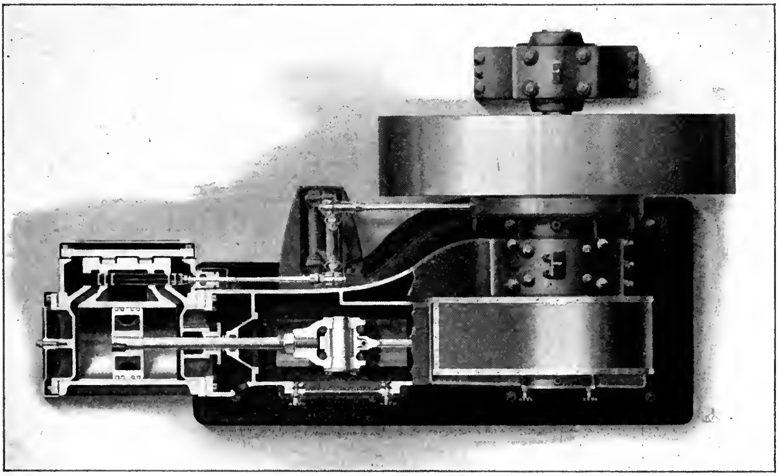


FIG. 60.

and by the various forms of balanced slide valves illustrated in Figs. 59 and 60 which work between the valve seat and a balance

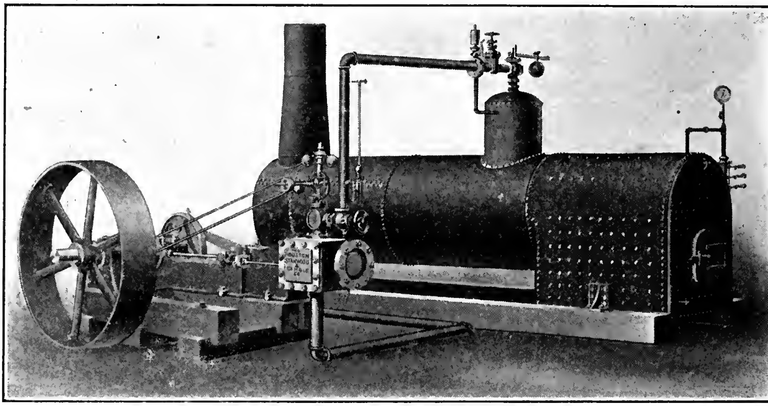


Fig. 61.

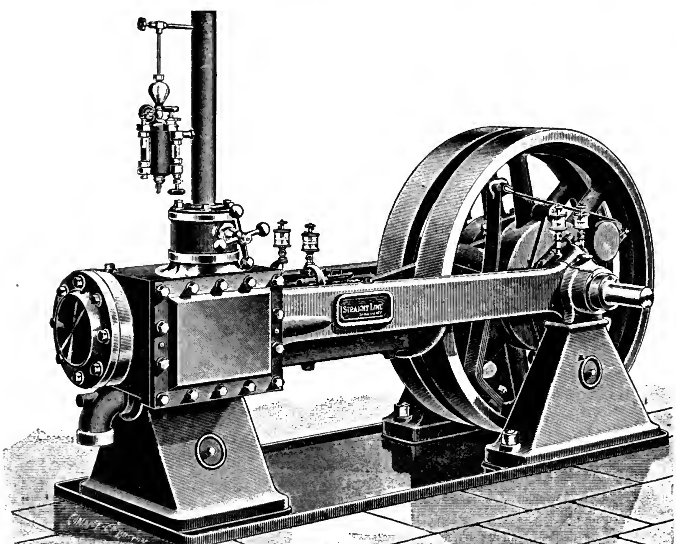


Fig. 62.

plate with an accurate mechanical fit. Fig. 61 shows a plain slide-valve engine. An engine with a balanced valve is illustrated in Fig. 62.

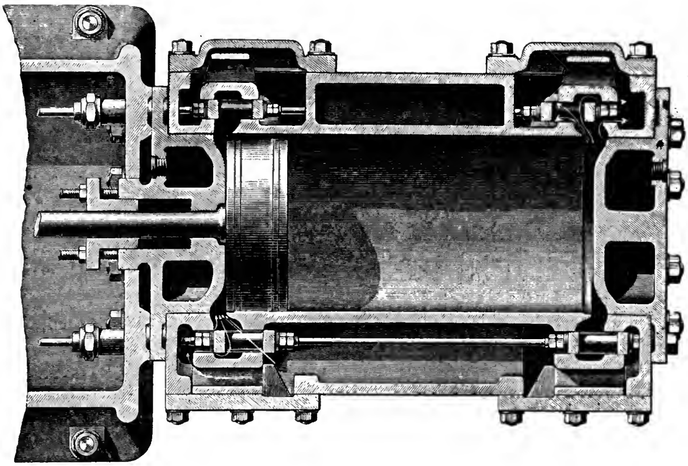


Fig. 63.

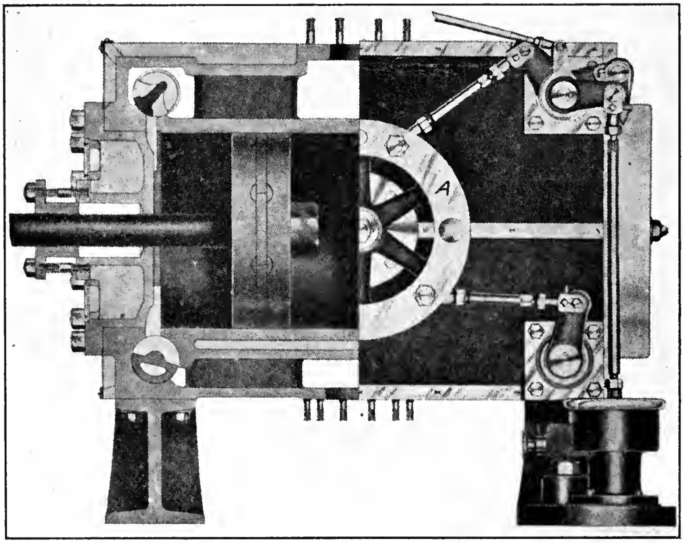


Fig. 64.

A steam-engine cylinder with separate steam valves and separate exhaust valves is given in Fig. 63, this form of valve having the advantage over the single valve in that the time of exhaust can be adjusted independently of the steam admission.

In large engines where high steam economy is of great importance the Corliss form of valve gear illustrated in Fig. 64 is used. The wrist plate A is oscillated by an eccentric and transmits its motion to the valve rods leading to the levers which operate the four valves of the engine. The two upper valves are the steam valves, while the two lower valves are the exhaust valves. In Fig. 64 one steam valve and one exhaust valve are shown in

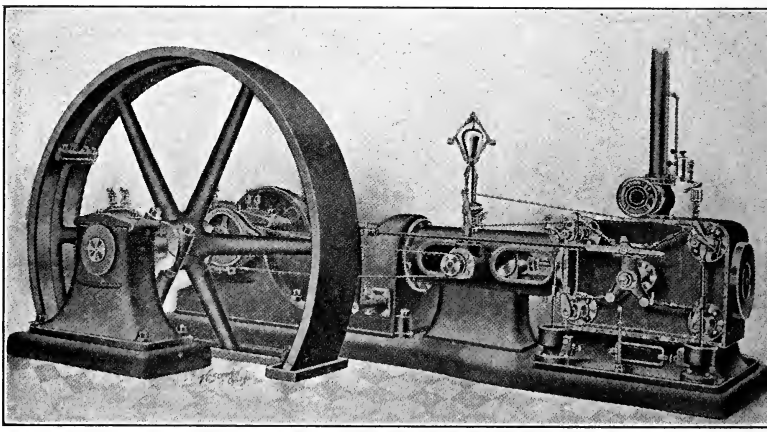


Fig. 65.

section. The exhaust valves are permanently connected to the wrist plate, while the steam valves are provided with a trip mechanism which releases the valve levers, thus closing the valve rapidly. Some forms of Corliss engines have both the steam and exhaust valves permanently connected to wrist plates; these types are called non-releasing Corliss engines. The general view of a Corliss engine may be seen from Fig. 65.

Valve Setting.—The object of setting valves on an engine is to equalize as much as possible the work done on both ends of the piston. A valve may be set so that both ends have the same lead, or so that the point of cut-off is the same at both ends.

Before a valve can be set, the dead centers for both ends of the engine must be accurately determined.

The method of setting an engine on dead center can best be understood by referring to Fig. 66. H represents the engine cross-head which moves between the guides marked G, N is the connecting rod, R the crank, F the engine flywheel, and O a stationary object.

To set the engine on dead center, turn the engine in the direction in which it is supposed to run, as shown by the arrow, until the cross-head is near the end of its head end travel, and make a small scratch mark on the cross-head and guide as at A. At the same time mark the edge of the flywheel and the stationary object opposite each other, as at B. Turn the engine past dead

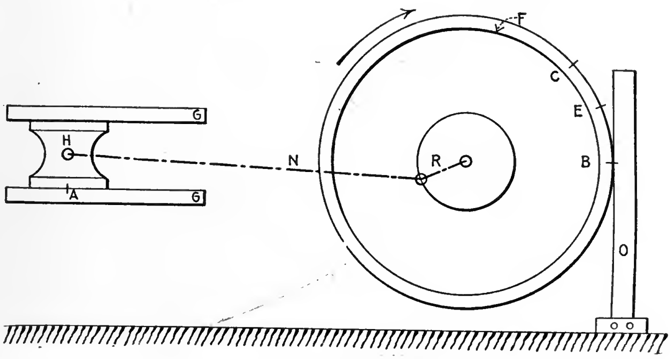


FIG. 66.

center, in the same direction as shown by the arrow, until the mark on the cross-head and that on the guide again coincide at A, and mark the flywheel in line with the same point on the stationary object, obtaining the mark C. The distance between the two marks on the flywheel is now bisected at E. If the mark E on the flywheel is now placed in line with the mark on the stationary object, the engine will be on the head end dead center. Similarly the crank end dead center can be found.

The stationary object may be a wooden board, or a tram may be used with one end resting on the engine bedplate and with the other end used for locating the marks B, C, and E on the flywheel.

If a valve is to be set for equal lead on both ends, set the engine on the dead center by the method given above, remove the steam chest cover, and measure the lead at that end. Move the engine forward to the other dead center and measure the lead again. If the lead on the two ends is not the same, correct the difference, by moving the valve on the valve stem, by moving the eccentric, or by moving both.

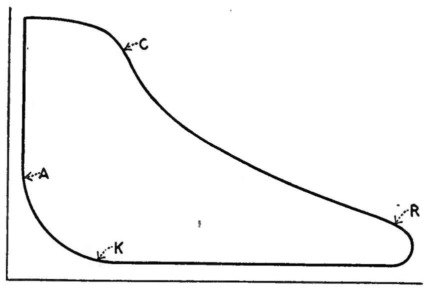


FIG. 67.

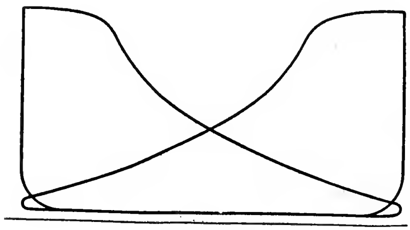


FIG. 68.

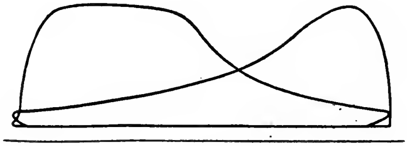


FIG. 69.

To set an engine for equal cut-off, turn the engine until the valve cuts-off at one end and mark the position of the cross-head on the guides. Then turn the engine until cut-off occurs on the opposite end and again mark this position of the cross-head on the guides. If the cut-off occurs earlier at one end than at the other, shorten the valve stem until the cut-off is equalized at both ends.

Steam-engine Indicator Cards.—In general the best method of setting valves is by means of a steam-engine indicator, explained in Chapter II and illustrated in Fig. 1. This form of instrument shows directly the action of the steam inside the engine cylinder, recording the actual pressure at each interval of the stroke.

An indicator card taken by means of an indicator is shown in Fig. 67. The events of stroke on the card are marked: admission A, cut-off C, release R, compression K. Fig. 68 shows indicator cards taken from two ends of a cylinder with a valve properly set, while Fig. 69 shows indicator cards taken from an engine where the valve is poorly set.

Classification of Steam Engines.—Steam engines are classified according to the type of valve gear used into:

1. Plain slide or piston valve engines with throttling governor.
2. Automatic high-speed engines. Under this head are included engines using piston valves or some form of balanced slide valve with flywheel governor.
3. Corliss slow-speed engines. Under this classification are included Corliss or other engines which are arranged with releasing steam valves, and which operate at a speed of 150 revolutions per minute or less. This type of valve gear is sometimes called the "drop cut-off" gear.
4. Corliss high-speed engines, which have non-releasing valves and operate at a speed of 200 r.p.m. or more.
5. Poppet valve engines.

Adaptability of Various Types of Steam Engines.—The plain slide valve engines are simple in construction, but are very uneconomical in the use of steam. They are still used to some extent in out-of-the-way places where facilities for repairing are poor, but are being replaced for most purposes by the automatic engines either with a piston valve or with a balanced slide valve. The cost of an automatic engine is not much greater than that of the plain slide valve engine and for powers up to 200 h.p. this type of engine is very desirable. For larger powers some form of Corliss engine or Poppet valve engine may be found more satisfactory.

Condensing and Non-condensing Engines.—Another method of classifying engines is into:

1. Condensing engines.
2. Non-condensing engines.

In case of the condensing engine the exhaust steam from the engine cylinder escapes into a condenser, where it is cooled and condensed into water, thus reducing the back pressure and producing a vacuum.

In the case of non-condensing engines the exhaust steam escapes into the atmosphere, or into heating coils, where it is utilized in heating buildings. The pressure of the exhaust steam in the case of the non-condensing engine exceeds atmospheric pressure.

Generally a condensing engine will use about 25 per cent. less steam than a non-condensing engine of the same size on account of the lower back pressure. Small engines are very seldom operated condensing, as the gain in economy is usually more than balanced by the increased first cost of the equipment and by the greater complications of the power plant.

Losses in Steam Engines.—The main losses in a steam engine are:

1. Loss in pressure as the steam is transferred from the steam boiler to the engine cylinder due to the throttling action in the steam pipe and ports.
2. Leakage past piston and valve.
3. Losses due to the condensation of steam in the cylinder during part of the stroke.
4. Radiation losses which take place when the steam passes through the steam pipes from the boiler to the cylinder and also while the steam is in the cylinder.
5. Losses of heat in the exhaust steam.
6. Mechanical losses due to the friction of the moving parts.

Of the above losses those due to the heat carried away in the exhaust steam are greatest and are usually 75 per cent. or more of the heat supplied in the steam. Part of this heat can be used for such purposes as the heating of feed water before it enters the boiler, for heating buildings, or in using the exhaust steam in connection with various manufacturing processes.

The other great loss is that due to the condensation of steam which takes place when the entering steam comes in contact with the cylinder walls which are at the temperature of the exhaust steam. This loss can be reduced to a considerable extent by having the steam entering the cylinder as dry as possible. Another method for reducing this loss, which is used in connection with large engines, is to compound the engine.

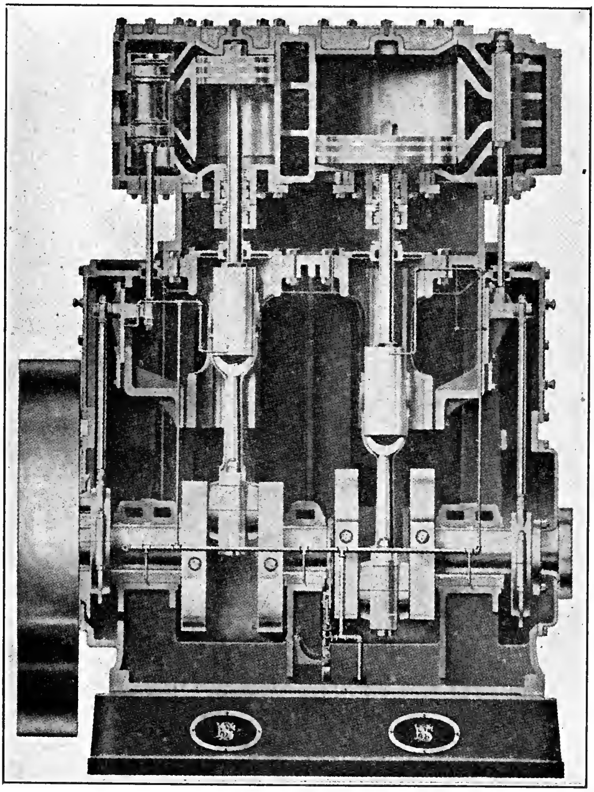


FIG. 70.

By compounding is meant the sub-division of the expansion of the steam into two or more cylinders. The steam on leaving the boiler enters the high-pressure cylinder, is partly expanded and then enters one or more cylinders where its expansion is completed to the exhaust pressure. The range of pressures in each cylinder of a compound engine being less than is the case of a simple, or one-cylinder engine, the temperature difference between the incoming and outgoing steam is less. This lower temperature range decreases the condensation of the steam in the cylinder. The gain in economy does not compensate for the increase first cost of compound engines as compared with simple engines in sizes under 200 h.p. A compound engine is illustrated in Fig. 70.

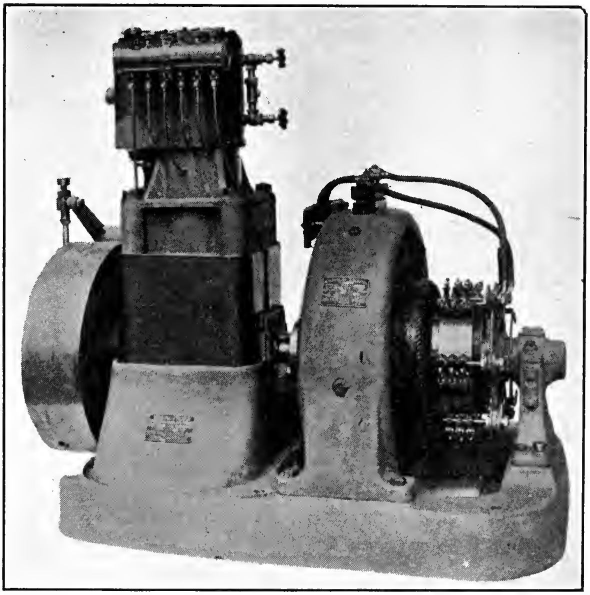


Fig. 71.

Radiation losses in the steam pipes leading from the boilers to the engines can be reduced to a minimum by covering the pipes. A good pipe covering will save the latent heat in the steam that would otherwise be lost, will keep the steam drier and will pay for itself in a very short amount of time.

The cylinders of most steam engines are now jacketed with some good non-conductor of heat and this loss is very small.

Mechanical losses in steam engines can be reduced by proper lubrication. Oil can be applied to the various parts by separate sight-feed lubricators and grease cups. Another method, illustrated in Fig. 71, is to connect an oil tank conveniently located with the various parts by adjustable sight-feed tubes, allowing different rates of feed to the various bearings. Still another method is to enclose some of the parts and make them self-oiling.

The losses due to leakage past the piston and valves are usually very small in well designed engines with balanced Corliss or Poppet valves. The various forms of balanced slide valves can be kept tight by means of balance plates.

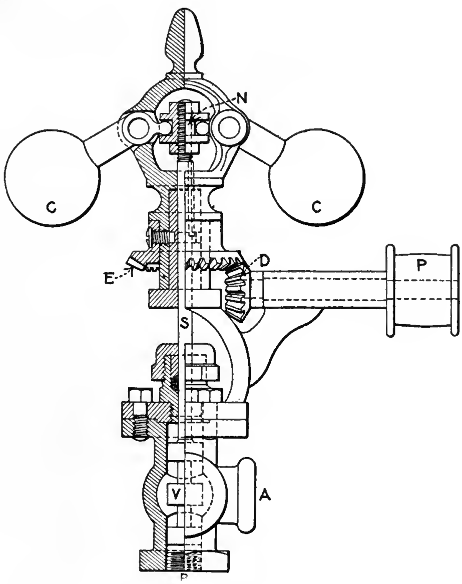


Fig. 72.

Steam-engine Governors.—The function of a governor is to control the speed of rotation of a motor irrespective of the power which it develops. In the steam engine, the governor maintains a uniform speed of rotation either by varying the initial pressure of the steam supplied, or by changing the point of cut-off and hence the portion of the stroke during which steam is admitted.

Governors which regulate the speed of an engine by varying the initial pressure of the steam supplied to the engine are called

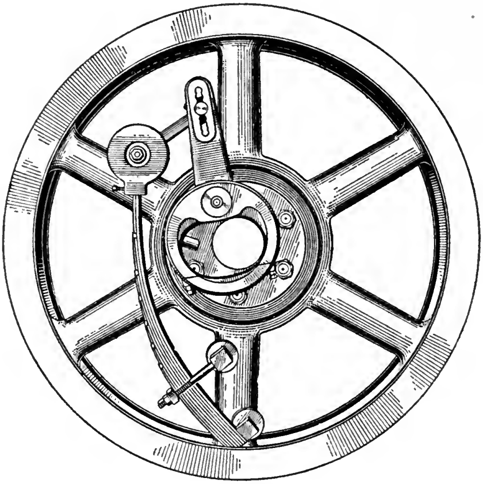


Fig. 73.

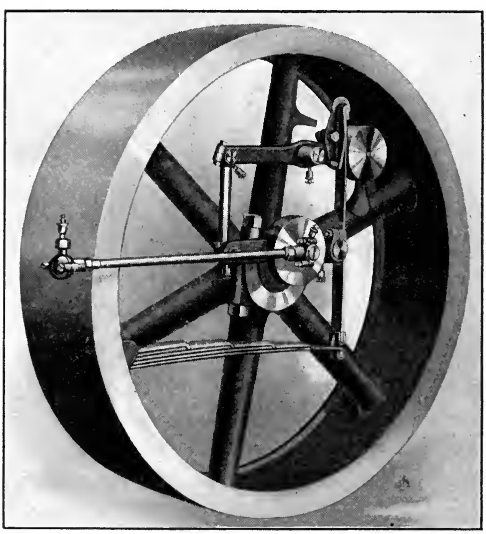


Fig. 74.

throttling governors. This is the simplest form of governor and is used mainly on engines of the plain slide-value type. The external appearance of a governor of this type is illustrated in Fig. 61. In Fig. 72 is given a section of a throttling governor, showing details. This form of governor is attached to the steam pipe at A and is connected to the engine cylinder at B, so that the steam must pass the valve V before entering the engine. The valve V is a balanced valve and is attached to a valve stem S,

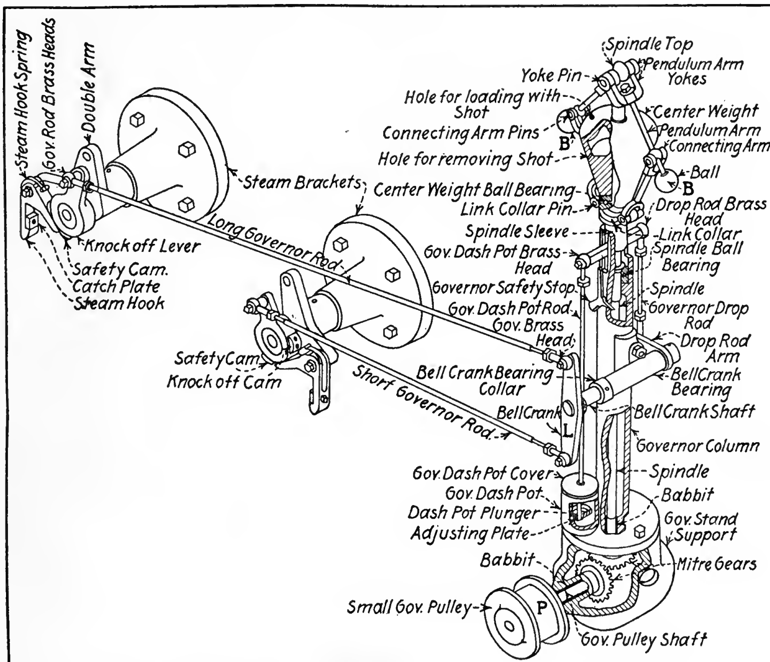


Fig. 75.

at the upper end of which are two balls C C. The valve stem and balls are driven from the engine shaft by a belt, which is connected to the pulley P, and which in turn runs the bevel gears D and E. As the speed of the engine is increased the centrifugal force makes the balls fly out, and in doing so they force down the valve stem S, thus reducing the area of the opening through the valve, and the steam to the engine is throttled.

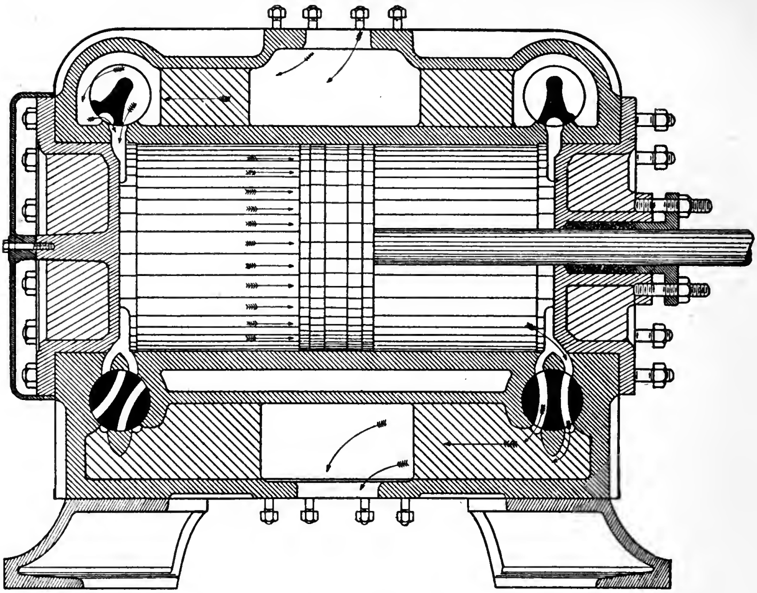


Fig. 76.

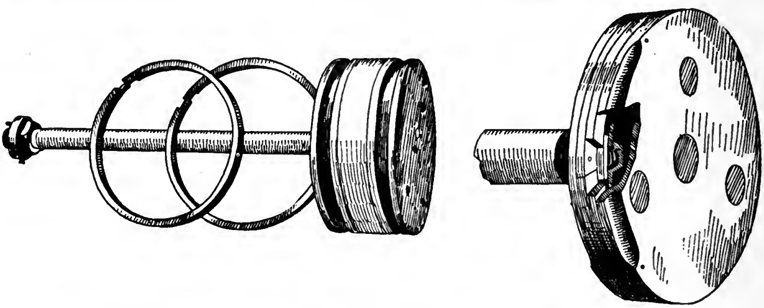


Fig. 77.

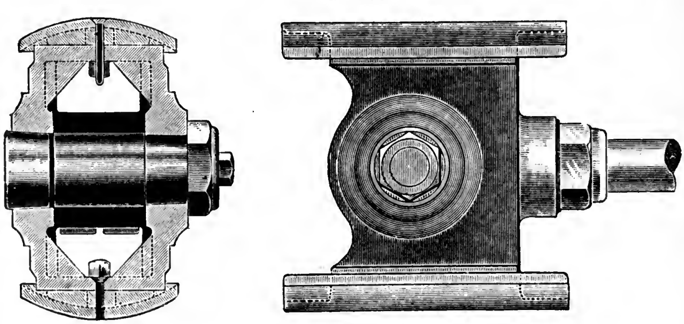


Fig. 78

As soon as the engine begins to slow down, the balls increase the steam opening through the valve V. The speed at which the steam is throttled can be changed within certain limits by regulating the position of the balls by means of the nut N.

Most of the better engines are governed by varying the point of cut-off and hence the total volume of steam supplied to the cylinder.

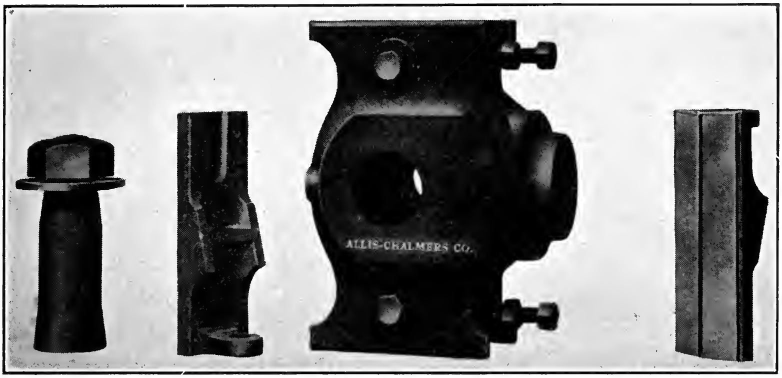


FIG. 79.

In high-speed automatic engines this is accomplished by some form of flywheel governor which is usually placed on the engine shaft, and which controls the point of cut-off by changing the position of the eccentric. Figs. 73 and 74 show two forms of

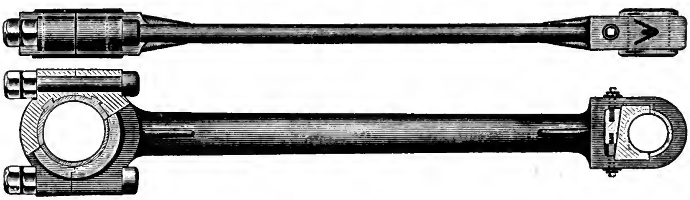


FIG. 80.

flywheel governors. As the speed of the engine increases, the governor weights are thrown outward by centrifugal force, moving the eccentric by means of levers and thus changing the time during which steam is admitted into the engine cylinder.

The general construction of governors for Corliss engines is illustrated in Fig. 75. As the speed of the engine increases the balls B B, which are driven from the engine shaft by a belt which is connected to the small governor pulley P, fly out moving the bell crank lever L, which in turn changes the position of the knock-off cam, unlatching the gear and releasing the valve.

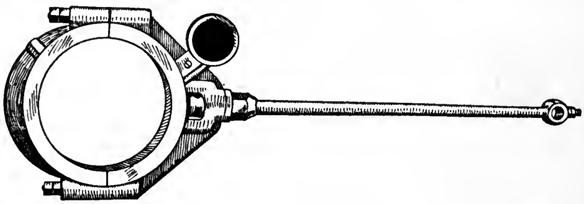


FIG. 81.

Engine Details.—The general construction of steam-engine cylinders can be seen from the previous illustrations. A section through a cylinder of a Corliss engine, showing valves, is shown in Fig. 76. Steam-engine cylinders are made of cast iron. As the cylinder wears it has to be rebored so as to maintain true inside surfaces. The thickness of the cylinder walls should not only be strong enough safely to withstand the maximum steam

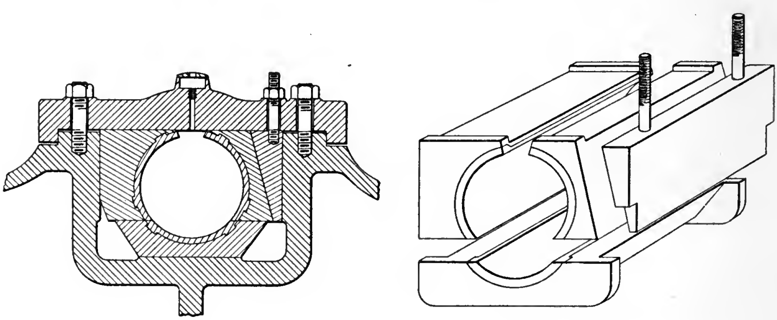


FIG. 82.

pressure, but should allow for reboring. All steam-engine cylinders should be provided with drip cocks at each end in order to drain the cylinder and steam chest when starting.

A good piston should be steam tight and at the same time should not produce too much friction when sliding inside of the engine cylinder. The piston is usually constructed somewhat smaller than the inside diameter of the engine cylinder, and is made tight by the use of split cast iron packing rings. In Fig.

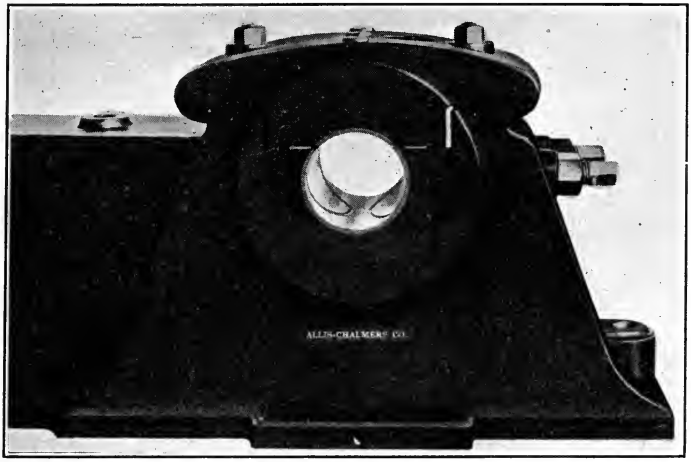


Fig. 83.

77 is illustrated a piston with its packing rings leaning against the piston rod; also a piston with the rings in place.

The general construction of steam-engine cross-heads is illus-

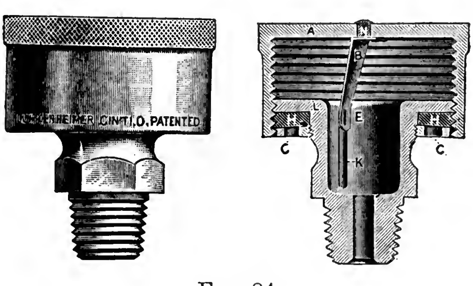


Fig. 84.

trated in Figs. 78 and 79. All cross-heads should be provided with shoes which can be adjusted for wear. The method of accomplishing this is illustrated in Fig. 79.

Figure 80 shows a connecting rod. It is connected at one end with the cross-head and at the other with the crank-pin. A connecting rod should be so constructed that the wear on its bearings can be taken up. This is usually accomplished by wedges and set-screws as illustrated.

The construction of several types of cranks can be seen from Figs. 58 and 70. Some engines have their cranks located between the two bearings of an engine, and are called center crank engines. Engines which have the cranks located at the end of the shaft and on one side of the two bearings are called side-crank engines.

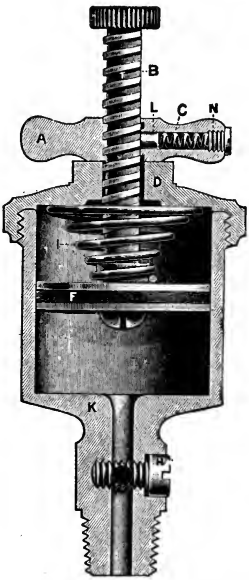


Fig. 85.

Fig. 86.

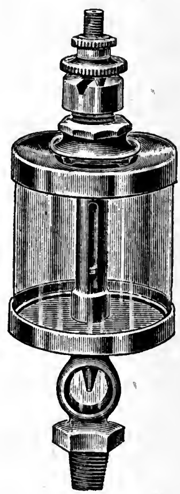


Fig. 87.

The eccentric is a special form of crank. It is usually set somewhat more than 90 degrees ahead of the crank and gives motion to the valve or valves in the steam chest of the engine. The eccentric is a cast-iron disc through which the shaft passes and which gives motion to the valve. Fig. 81 shows an eccentric rod and strap.

The main bearings of steam engines are illustrated in Figs. 82 and 83. These bearings are usually made in three or four parts and can be adjusted for wear by means of wedges and set screws fastened with lock-nuts.

Engine Auxiliaries.—Under this head will be explained lubricators, steam separators, exhaust-pipe heads and condensers. Other engine auxiliaries are treated in other parts of the book.

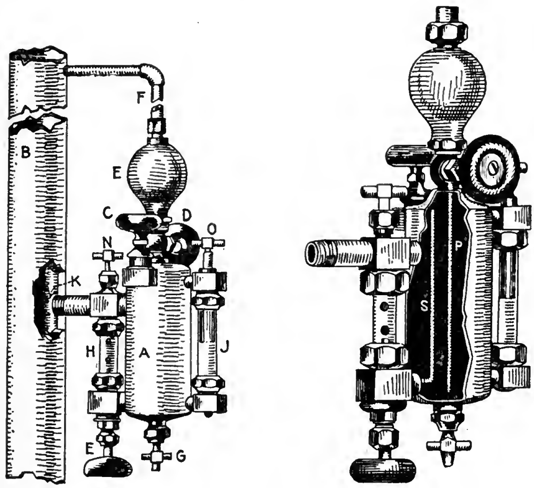


FIG. 88.

Lubricators.—The subject of lubricating the moving parts of an engine was treated to some extent in connection with the discussion of mechanical losses in steam engines.

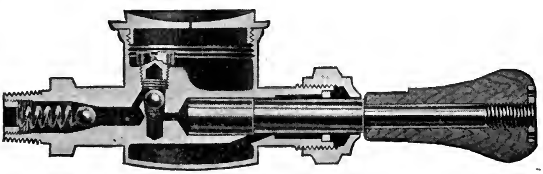


FIG. 89.

Bearings may be lubricated by grease cups illustrated by Figs. 84 and 85. The first type is used on stationary bearings, the grease being forced out by screwing the cap down by hand. The type illustrated in Fig. 85 is automatically operated, and is used for the lubrication of crank pins.

If oil is used, a plain oil cup illustrated in Fig. 86 can be employed, or some form of sight-feed lubricator, as shown in Fig. 87. By means of the sight-feed types the flow of oil can be regulated and the drops of oil issuing from the lubricator can be seen.

For the lubrication of steam-engine cylinders some form of sight-feed automatic steam lubricator, as illustrated in Fig. 88, should be employed. This form of lubricator is used to introduce a heavy oil into the steam entering the cylinder. This oil is a

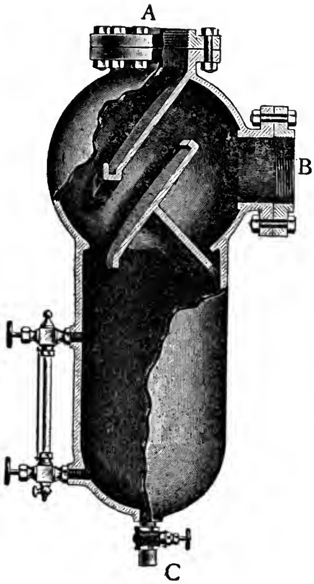


FIG. 90.

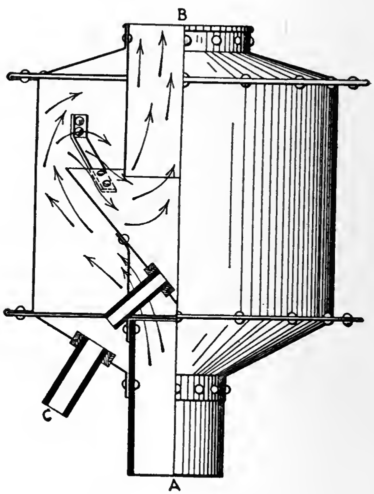


FIG. 91.

specially refined heavy petroleum oil which will neither decompose, vaporize or burn when exposed to the high temperature of steam. Steam from the pipe leading to the cylinder B is admitted through the pipe F to the condensing chamber E where it is condensed and falls through the pipe P to the bottom of the chamber A. The oil which is contained in chamber A rises to the top, is forced through the tube S, ascends in drops through the water in the gage glass H, and into the steam pipe K leading to the steam chest. The amount of oil fed is regulated by the needle valve G. T shows the amount of oil in the chamber A. In order to fill the chamber A, the valves on the pipes F and H are closed, the water is drained out through G, and the cap D is removed for receiving the oil.

Figure 89 shows a hand oil pump which is sometimes used to admit oil into the cylinder of an engine when starting.

Steam Separators.—The function of a steam separator is to remove any water which may be contained in the steam before it enters the engine cylinder. A separator placed in the exhaust pipe of an engine will remove a large part of the oil, making the

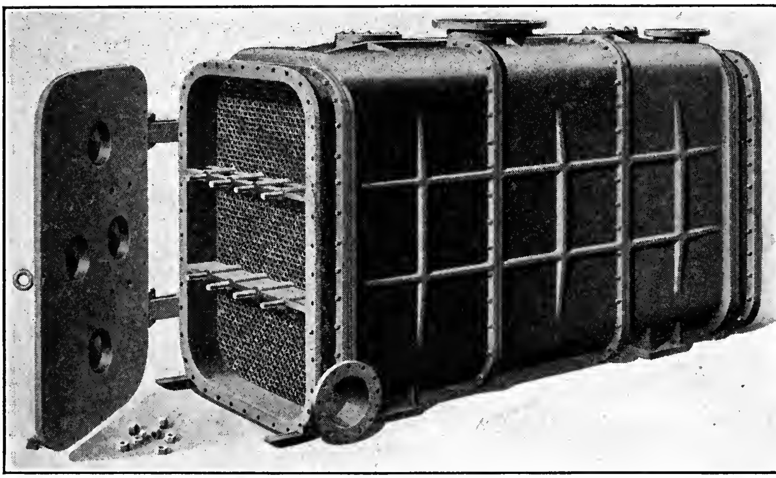


Fig. 92.

exhaust steam more suitable for heating, manufacturing purposes, or for use in steam boilers after condensation.

The importance of having the steam entering the engine cylinder as dry as possible was explained in an earlier part of this chapter. A good steam separator, if of sufficient size, will insure fairly dry steam and should be used in connection with all stationary steam engines.

Figure 90 shows in section one form of steam separator. The wet steam enters at A, strikes the deflecting plates, its velocity is decreased and the entrained water, which is heavier than the steam, falls to the bottom and is removed at C by means of a trap. The dry steam passes out at B.

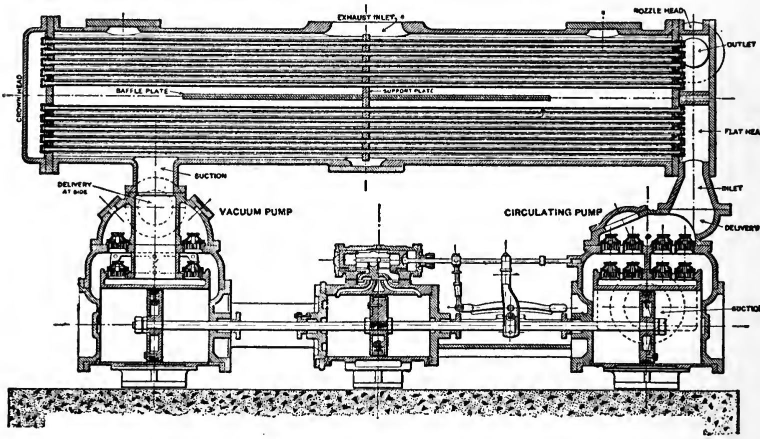


FIG. 93.

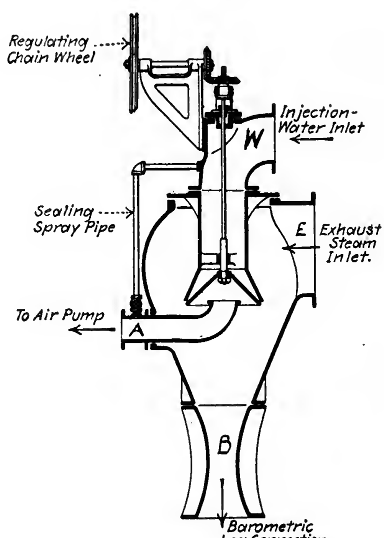


FIG. 94.

Exhaust Pipe Heads.—The function of an exhaust pipe head is to prevent the discharge of oil and water from exhaust pipes of steam engines. The discharge of oil and water from an unprotected pipe will disfigure buildings, will reduce the life of power-house roofs and in the winter time it is a nuisance on account of the accumulation of ice upon the buildings and pavement due to the escape of water. The principle of an exhaust head is illustrated in Fig. 91. The exhaust pipe is connected at A. The steam is hurled against the inverted cone and its direction is changed, the dry steam escaping at B, while the heavier water and oil are dicharged through the pipe C.

Condensers.—Condensers for the use in connection with steam engines are divided into two types, known as the surface and direct-contact or jet condenser.

The details of construction of the surface condenser are illustrated in Figs. 92 and 93. Fig. 92 shows a surface condenser with one of the heads removed. The various auxiliaries of the surface condenser are illustrated in Fig. 93. The cooling water is forced through the tubes of the condenser by the circulating pump and condenses the steam in contact with the other side of the tubes. The steam enters the condenser at the exhaust inlet and is drawn off by a vacuum pump, often called an air pump. In the figure both the circulating and air pumps are driven by one steam cylinder.

The jet condenser differs from the surface types in that the steam comes in direct contact with the water by which it is condensed. One form of jet condenser is illustrated in Fig. 94. The exhaust steam from the engine enters at E and is condensed by coming in contact with the water entering at W. The condensed steam goes out at B, while A is connected to an air pump for the removal of any air which might enter the condenser with the steam or with the condensing water.

The jet condenser is much simpler than the surface condenser. The surface condenser has the advantage in that its cooling water does not come in direct contact with the steam to be condensed. For this reason surface condensers are used where the condensed steam is returned to the boiler, and where the cooling water is salty, muddy or otherwise unfit for steam making.

Steam Turbines.—The steam turbine differs from the steam engine described, in that it produces rotary motion directly and without any reciprocating parts. It consists of a stationary part and one or more wheels with vanes which are rotated by steam striking the vanes. The elastic force of the steam, instead of acting on a piston, is exerted on the steam itself, producing a drop in pressure and a steam jet of high velocity.

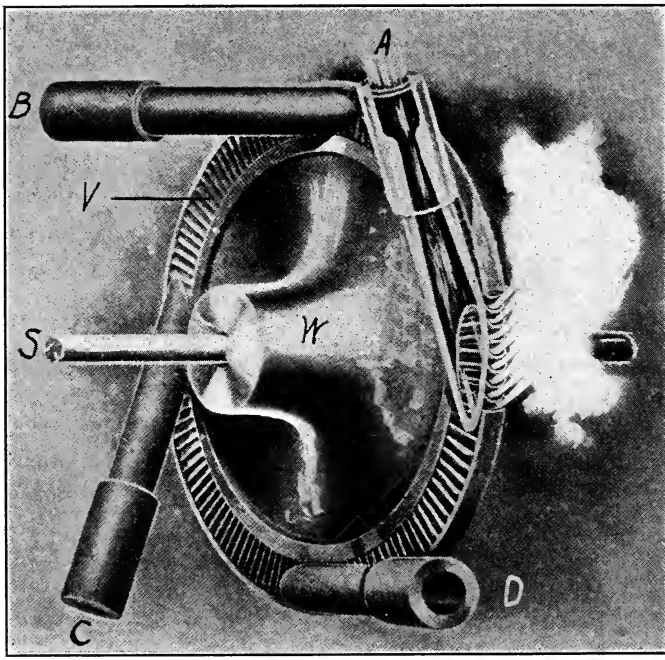


Fig. 95.

The steam turbine is best adapted for the driving of electrical generators, centrifugal pumps and air compressors, cream separators and other machinery requiring a high-speed rotation.

In large sizes the steam turbine is somewhat more economical than the reciprocating steam engine and occupies considerably less space. The steam turbine requires no internal lubrication, and thus the exhaust steam can be used again in the boiler without requiring oil filtration. For large power plants the steam turbine has several other advantages.

While there are a great many makes of turbines, they vary only in minor details, and belong to either the impulse type or the reaction type. In the impulse type the steam expands only in stationary nozzles, while in the reaction type part of the expansion takes place in stationary vanes and part in the vanes of the rotating wheels.

The action of one form of impulse steam turbine much used for the driving of cream separators is illustrated in Fig. 95. A, B, C

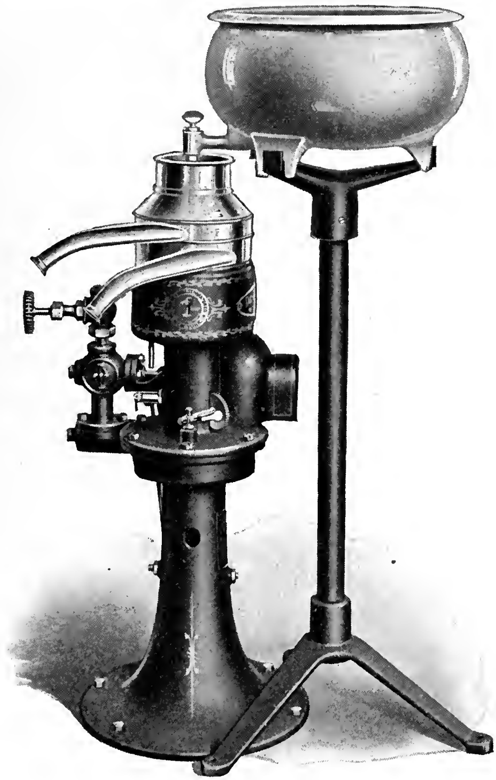


FIG. 96.

and D are stationary nozzles in which the steam is completely expanded and strikes the vanes V, giving a direct rotary motion to the wheel W and also to the shaft S.

The application of this type of steam turbine to the driving of a cream separator is illustrated in Fig. 96.

Installation and Care of Steam Engines.—Foundations for steam engines are usually put in by the purchaser, the manufacturer furnishing complete drawings for that purpose. Drawings of a board template are also included. A template is a wooden frame which is used in locating the foundation bolts and for holding them in position while building the foundation.

Before starting on the foundation a bed should be prepared for receiving it. The depth of bed depends on the soil. If the soil is rocky and firm, the foundation can be built without much difficulty. When the soil is very soft piles may have to be driven. The piles should be excavated to a depth of about two feet and the space filled with concrete.

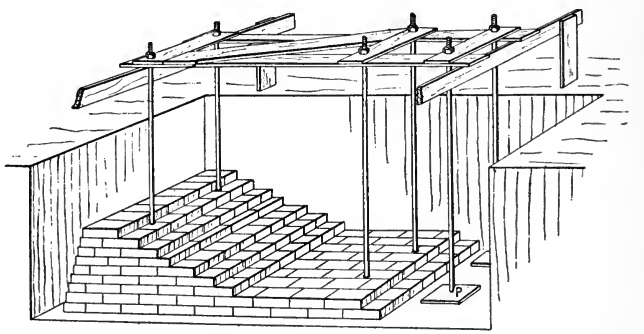


FIG. 97.

The wooden template is then constructed from the drawings holes being bored for the insertion of foundation bolts.

Foundations may be built of brick or of concrete. If of concrete the mixture should consist of one part of cement, two parts of sharp sand and four parts of crushed stone. The stone should be of a size as will pass through a 2-in. ring. In starting on a concrete foundation, a wooden frame of the exact shape of the foundation is built. This template is then placed in position in the manner shown by Fig. 97, and the bolts are put in, the heads of the bolts being at the bottom in recesses of cast-iron anchor plates marked P. Often the foundation bolts are threaded at both ends and the anchor plates are held in place by square nuts. A piece of galvanized iron pipe should be placed around each bolt, so as to allow the bolts to be moved slightly to pass through the holes in the engine bedplate, in case an error should occur in the placing of the bolts, or in the location of the bolt holes in the engine bedplate.

With the frame, template and foundation bolts in place, the concrete can now be poured and tamped down. After the concrete has set the template is removed and the foundation is made perfectly level. It is well to allow a concrete foundation to set several weeks before placing any weight on it.

When the foundation is ready, the engine is placed in position and leveled by means of wedges. The nuts on the bolts are now screwed down and the engine is grouted in place by means of neat cement, this serving to fill any crevices and to give the engine a perfect bearing on the foundation.

After erecting the engine and all its auxiliaries, including pipes, valves, cocks and lubricators, all the parts should be carefully examined and cleaned, and a coating of oil should be applied to all rubbing surfaces, cylinder oil being used for the wearing parts in the valve chest and cylinder.

Before the engine is operated for the first time, it is well to loosen the nuts and bolts, adjust bearings, and turn the engine over slowly until an opportunity has been given for any inequalities due to tool and file marks to be partially eliminated, and also to prevent heating that might occur if there was an error in adjustment.

When the engine is ready to start, the boiler valve should be slowly opened to allow the piping to warm up, but leaving the drain cock in the steam pipe, above the steam chest, open to permit the escape of condensation. While the piping is being warmed up all the grease cups and lubricators are filled. Before opening the throttle valve, all cylinder and steam chest drain cocks should be opened to expell water, and the flow or oil started through the various lubricators. The throttle valve is then opened gradually, and both ends of the engine warmed up. This in the case of a single-valve engine can be accomplished by turning over the engine slowly by hand to admit steam in turn to each end of the cylinder. In starting a Corliss engine the eccentric is unlocked from the pin on the wrist plate and the wrist plate is rocked by hand sufficiently to allow steam to pass through each set of valves. The drain cocks are closed soon after the throttle is wide open and the engine up to speed, providing steam is blowing through.

When stopping an engine, close the throttle valve. As soon as engine stops, close the lubricators, wipe clean the various parts, examining all bearings and leaving engine in perfect condition ready to start.

The above instructions apply to non-condensing engines. If the engine is to be operated condensing, the circulating and air pumps should be started while the engine is warming up. The other directions apply with slight modifications to all types of steam engines.

In regard to daily operation, cleanliness is of great importance. No part of the engine should be allowed to become dirty and all parts must be kept free from rust. It is well to draw off all the oil from bearings quite frequently and to clean them with kerosene before refilling with fresh oil. In starting it is well to give the various parts plenty of oil, but the amount should be decreased as the engine warms up.

Competent engineers usually make a practice of going over and cleaning every bearing, nut, and bolt, immediately on shutting down. This practice not only keeps the engine in first-class condition, as regards cleanliness, but enables the operator to detect the first indication of any defect that, if overlooked, might result seriously.

If a knock develops in a steam engine, it should be located and remedied at once. Knocking is usually due to lost motion in bearings, worn journals or cross-head shoes, water in the cylinder, loose piston or to poor valve setting. Locating knocks in steam engines is to a great extent a matter of experience and no definite rules can be laid down which will meet all cases.

However, the beginner may, by careful attention to the machine, learn to trace out the location of a knock in a comparatively short time. He must, however, bear in mind that he cannot rely on his ear for locating it, as the sound produced by a knock is, in many cases, transmitted along the moving parts, and apparently comes from an entirely different point.

A knock, due to water in the cylinder, is usually sharp and crackling in its nature, while that in the case of a crank or a cross-head pin is more in the nature of a thud. If the knock should be due to looseness of the main bearings, the location may be detected by carefully watching the flywheel, while if the cross-heads are loose in the guides the observer may be able to detect a motion crossways of the cross-head, but it is not likely that he can do this with accuracy in the case of a high-speed engine, and the cross-head should be tested when the engine is at rest. *In no case should any adjustments be made in bearings or moving parts of an engine unless the machine is at standstill or being turned by hand; never when under its own power.*

The heating of a bearing is always due to one of five causes:

1. Insufficient lubrication due to insufficient quantity of oil, wrong kind of oil, or lack of proper means to distribute the oil about the bearings.
2. The presence of dirt in the bearings.
3. Bearings out of alignment.
4. Bearings improperly adjusted; they may be either too tight or too loose.
5. Operation in a place where the temperature is excessive.

In case a bearing should run hot and it is very undesirable to shut down, it is oftentimes possible to keep going by a liberal application of cold water through the entire heating surface or surfaces. It is sometimes possible to stop heating by changing from machine oil to cylinder oil which has a higher flash point.

Should a bearing, particularly a large one, be overheated to the extent that it is necessary to shut down the engine, do not shut down suddenly or allow the bearing to stand any length of time without attention. This is particularly important in the case of babbitted bearings, as the softer metal of the bearings will tend to become brazed to, or fused with, the harder metal of the shaft, and it may be necessary to put the engine through the shop before it can be used again.

In case of the necessity of shutting down for a hot bearing, first remove the load, then permit the engine to revolve slowly under its own steam until the bearing is sufficiently cool to permit the bare hand to rest on it, or until the box can be loosened sufficiently to remove the soft metal of the bearing from close contact from the shaft.

The presence of water in the cylinder is always a source of danger, and care should be taken that the water of condensation is thoroughly drained from the cylinder when the engine is first started, at shutting down, and at regular intervals throughout the operation. An accumulation of water may readily result in the blowing out of a cylinder head with its resultant loss to property and possibly of life. There are several appliances now on the market which automatically safeguard the cylinder head by providing a weak point in the drain system which will relieve the excess pressure before the cylinder head gives way.

CHAPTER VI

GAS AND OIL ENGINES

The Internal Combustion Engine.—The internal combustion engine, commonly called a gas engine, differs from the steam engine, in that the transformation of the heat energy of the fuel into work takes place within the engine cylinder. The fuel may be gasoline, kerosene, crude petroleum, alcohol, illuminating gas, or some form of power gas.

In order to form an explosive mixture in the cylinder, air must be mixed in certain proportions with the fuel, and this can only be accomplished when the fuel is in the gaseous state, or is a mist of liquid fuel easily vaporized at ordinary temperatures. Thus the essential difference between internal combustion engines using the various fuels is in the construction of the device for preparing the fuel before it enters the engine cylinder. If the fuel is a gas, only a stop valve is necessary between the source and the gas engine admission valve. The device for preparing liquid fuels depends on the character of the fuel, a heavy fuel requiring heat while a volatile fuel is easily vaporized at ordinary temperatures by being broken up in a fine mist. If the fuel is in the solid form, like coal, it must be converted into a gas by use the of a gas producer, to be described later, before it can be used in the gas engine cylinder.

After the mixture is drawn into the cylinder, it is prepared for ignition by compressing and intimately mixing the fuel with the air at one end of the engine cylinder. Ignition of the highly compressed explosive mixture is followed by a great rise in pressure which is utilized in producing work.

The Gas-engine Cycle.—The series of events which are essential for carrying out the transformation of heat into work is called the cycle of an engine. The gas-engine cycle mostly used, the Otto cycle, comprises five events which are:

1. The mixture of fuel and air must be drawn into the engine cylinder.

2. The mixture must be compressed.
3. The mixture must be ignited.
4. The ignited mixture expands doing work.
5. The cylinder must be cleaned of burned gases in order to receive a fresh mixture.

The above five events in the order explained are usually called: suction, compression, ignition, expansion, and exhaust.

There is another commercial gas-engine cycle, the Diesel, which is used in certain types of oil engines. The Diesel cycle also requires five events, and differs from the Otto cycle in that air without fuel is compressed in the engine cylinder to such a great pressure that the temperature resulting is sufficiently high to ignite the fuel automatically, as it is sprayed by an auxiliary pump into the engine cylinder.

The compression pressures carried in engines working on the Diesel cycle are 500 to 700 lb. per square inch, while those carried in engines working on the Otto cycle and with the same fuels are 55 to 80 lb. per square inch.

Classification of Gas Engines.—Gas engines are divided into two classes, according to the number of piston strokes required to carry out the five events of the gas-engine cycle. To one class belong all engines which require four complete strokes of the piston, or two complete revolutions of the crank-shaft to carry out the five events of the gas-engine cycle. These engines are called four-stroke cycle engines. The two-stroke cycle-engine works on the same gas-engine cycle as the four-stroke cycle engine, only the mechanism is modified so as to carry out the five events in only two strokes of the piston.

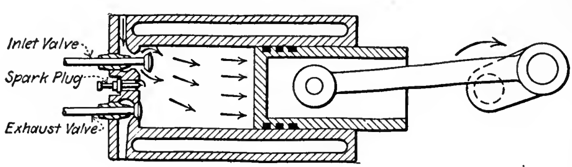


Fig. 98.

The Four-stroke Cycle.—The action of an internal combustion engine working on the four-stroke Otto cycle is illustrated in Figs. 98 to 102.

1. Suction of the mixture of air and gas through the inlet

valve takes place during the complete outward stroke of the piston, the exhaust valve being closed. This is shown in Fig. 98.

2. On the return stroke of the piston, shown in Fig. 99, both the inlet and exhaust valves remain closed and the mixture is

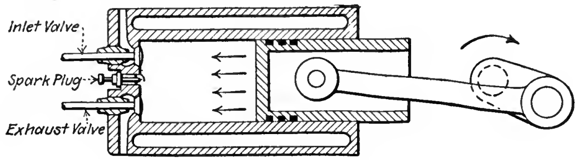


Fig. 99.

compressed between the piston and the closed end of the cylinder. Just before this stroke of the piston is completed the compressed mixture is ignited by a spark as illustrated in Fig. 100, and rapid combustion, or explosion takes place.

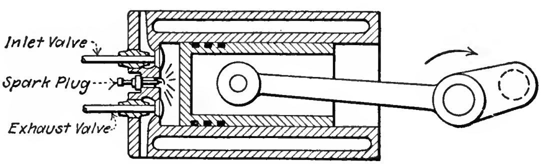


Fig. 100.

3. The increased pressure due to the rapid combustion of the mixture drives the piston on its second forward stroke, which is the power stroke. This is shown in Fig. 101. Both

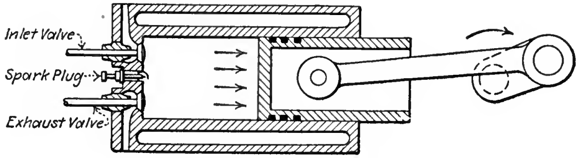


Fig. 101.

valves remain closed until the end of the power stroke, when the exhaust valve opens and communicates the cylinder with the atmosphere.

4. The exhaust valve remains open during the fourth stroke

called the exhaust stroke, Fig. 102, and the burned gases are driven out from the cylinder by the return of the piston.

An indicator diagram, taken from a four-stroke cycle engine, using gasoline as fuel, is illustrated in Fig. 103. IB is the suction stroke, BC the compression stroke, CD shows the ignition event, DE is the power stroke and EI is the exhaust stroke. The

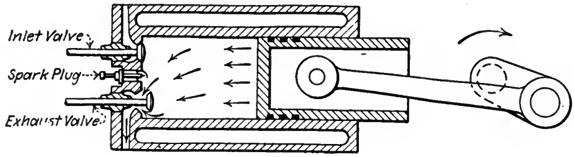


FIG. 102.

direction of motion of the piston during each stroke is illustrated in each case by arrows. Lines AF and AG were added to the indicator diagram, the first is the atmospheric line while AG is the line of pressures. From Fig. 103 it will be noticed that part of the suction stroke occurs at a pressure lower than atmospheric. The reason for this is that a slight vacuum is created

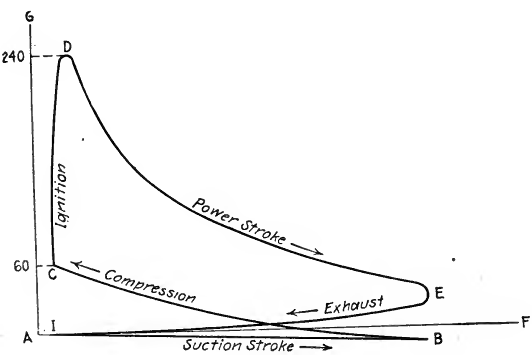


FIG. 103.

in the cylinder by the piston moving away from the cylinder head. This vacuum helps to draw or suck the mixture into the cylinder.

The engine working on the four-stroke cycle requires two complete revolutions of the crank shaft, or four strokes of the piston to produce one working stroke. The other three are not only idle strokes, but power is required to move the piston through these strokes, and this has to be furnished by storing extra momentum in heavy flywheels. Several attempts were made from time to time to produce an internal combustion engine by modifying the Otto or Diesel gas-engine cycles, so that the working stroke would occur more frequently. This has resulted

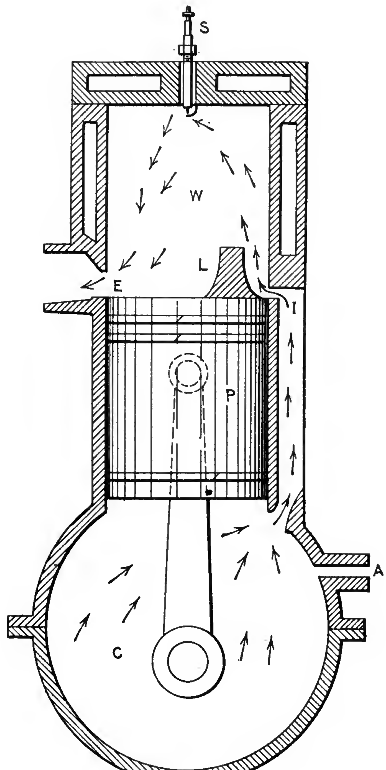


FIG. 104.

in the so-called two-stroke cycle engine, to be explained in the next section, which completes the cycle in two strokes requiring only one complete revolution of the crank.

The Two-stroke Cycle.—The two-stroke cycle engine carries out the gas-engine cycle in two strokes by precompressing the mixture of fuel and air in a separate chamber, and by having the events of expansion, exhaust and admission occur during the same stroke of the piston. The precompression of the mixture is accomplished in some engines by having a tightly closed crank case, and in other types by closing the crank end of the cylinder, and providing a stuffing box for the piston rod. Large two-stroke cycle engines are usually made double acting and an additional cylinder is provided for the precompression of the mixture.

The principle of the two-stroke cycle internal combustion engine is illustrated in Fig. 104. On the upward stroke of the piston P, a partial vacuum is created in the crank case C, and the explosive mixture of fuel and air is drawn in through a valve at A. At the same time a mixture previously taken into the upper part of the cylinder W is compressed. Near the end of this compression stroke, the mixture is fired from a spark produced by the spark plug S. This produces an increase in pressure which drives the piston on its downward or working stroke. The piston descending compresses the mixture in the crank case to several pounds above atmospheric, the admission valve at A being closed as soon as the pressure in the crank case exceeds atmospheric. When the piston is very near the end of its downward stroke, it uncovers the exhaust port at E and allows the burned gases to escape into the atmosphere. The piston continuing on its downward stroke next uncovers the port at I, allowing the slightly compressed mixture in the crank case C to rush into the working part of the cylinder W.

The distinctive feature of the two-stroke cycle engine is the absence of valves. The transfer port I from the crank case C to the working part of the cylinder W, as well as the exhaust port E, are opened and closed by the piston.

Comparison of Two-stroke Cycle and Four-stroke Cycle Engines.—To offset the advantages resulting from fewer valves and greater frequency of working strokes, the two-stroke cycle engine is usually less economical in fuel consumption and not as reliable as the four-stroke cycle engine. As the inlet port I is opened while the exhaust of the gases takes place at E, there is always some chance that part of the fresh mixture will pass out through the exhaust port. Closing the exhaust port too soon will cause a decrease in power and efficiency, on account of the mixing of the inert burned gases with the fresh mixture. By carefully proportioning the size and location of the ports, and by providing the piston with a lip L (Fig. 104) to direct the incoming mixture toward the cylinder head, the above losses may be decreased. In any case the scavenging of the cylinder cannot be as complete in the two-stroke cycle as in the four-stroke cycle engine, where one full stroke of the piston is allowed for the removal of the exhaust gases.

The two-stroke cycle engine can be made to run in either direction by a simple modification of the ignition timing mechan-

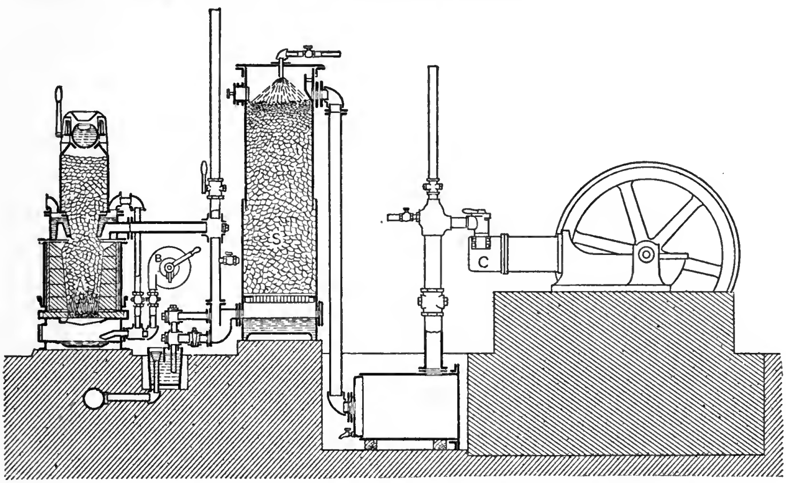


Fig. 105.

ism. This feature, and because of its light weight, makes the two-stroke cycle engine especially adaptable for the propulsion of small boats. For stationary purposes, in small and medium sizes, and for the propulsion of traction engines, automobiles and other vehicles, the four-stroke cycle engine is usually to be preferred on account of its reliability and somewhat better fuel economy.

Gas-engine Fuels.—Fuels for internal combustion engines may be classified as solid, liquid and gaseous. The value of a fuel for gas-engine use depends on the amount of heat liberated when the fuel is burned, on the cost of the fuel, and on the cost of preparing the fuel for use in the gas-engine cylinder.

As was explained in the earlier part of this chapter, the fuel entering the gas-engine cylinder must be in the form of a vapor or a gas. For this reason where a gaseous fuel can be obtained at low cost, the complications of the engine mechanism are reduced. In or near the natural gas regions, no other gas-engine fuel is a competitor of the natural gas. Also in connection with certain industrial processes, notably in the production of pig iron, certain gaseous fuels are obtained as a byproduct and are utilized with good results in gas engines. Illuminating gas is usually too expensive as a gas-engine fuel.

Where coal is cheap and petroleum oils are expensive an artificial gas, called producer gas, has been successful, and this type of gas is being used in large as well as comparatively small plants. An apparatus for making producer gas, called a gas producer, is illustrated in Fig. 105. A is a shell filled with coal or coke, and supplied with air and steam. Due to the thickness of the fuel bed the combustion of the fuel is incomplete and a combustible gas is formed. The steam supplied enriches the gas and prevents the formation of clinker by keeping down the temperature of the fuel bed. S is a scrubber used for cleaning the gas before it is admitted to the engine cylinder C. B is a blower which is used to furnish draft during the starting of the fire in the producer.

As a portable engine for small powers, the internal combustion engine using some liquid fuel has the greatest field of application. Such engines are especially suitable for intermittent work and are ideal for farm use.

The liquid fuels used in internal combustion engines are gasoline, kerosene, crude petroleum, fuel oil and alcohol.

Gasoline and Other Distillates of Crude Petroleum.—Gasoline and kerosene are among the lighter distillates of crude petroleum. The so-called distillates are obtained by boiling or refining crude petroleum, and condensing the vapors which are driven off at various temperatures.

The vapors which are condensed into gasoline are driven off at temperatures of 140 to 160° F. The various grades of kerosene are the condensed vapors, driven off at temperatures of 250 to 400°, and the heavy oils are driven off at still higher temperatures.

Of all petroleum distillates, gasoline is the most important fuel for small internal combustion engines. The yield of gasoline, however, is very small in comparison with the heavier distillates. By refining American petroleum, an average of less than 5 per cent. of gasoline is obtained and usually about 50 per cent. of kerosene. This makes gasoline more expensive than other petroleum fuels. However, as a fuel for small and portable engines it has the advantages of quick starting and greater reliability, which more than make up for the greater cost. Processes are now being perfected for extracting gasoline from natural gas, and there is little doubt but what gasoline will remain for many years to come the most important fuel for small internal combustion engines.

Gasoline has a flash point of 10 to 20° F. This means that it forms an inflamable vapor at that low temperature, provided a sufficient supply of air is present. For this reason care must be taken in the handling of gasoline. A good storage tank free from leaks and placed underground contributes greatly to the safety, as well as to the economical use of gasoline. When filling a gasoline storage tank or in handling gasoline, care must be taken not to have any unprotected flame nearby. In case gasoline takes fire at the engine or at the storage tank, it is best to extinguish it by means of wet sawdust. Sand or dirt will do in an emergency, but if it finds its way into the engine cylinder, it may cause considerable damage by cutting the rubbing surfaces.

The flash point of kerosene is 70 to 150° F., depending on the grade. As the flash point of oil is a measure of its safety, a kerosene of a lower flash point than 120° F. is dangerous for use as an illuminating oil in lamps. The lower the flash point of an oil the better it is for gas engine use, as less heat is required to vaporize it ready for use in the engine cylinder.

Very light gasoline has a specific gravity of from 0.65 to 0.74. The specific gravity of kerosene is 0.78 to 0.86, of crude oil 0.87 to 0.90 and of fuel oil 0.90 to 0.94. The specific gravity of petroleum fuels is usually given in degrees of the Baume hydrometer. The relations existing between the specific gravity of various liquid fuels, the degrees on the Baume hydrometer, and the weight of a fuel in pounds per gallon are given in Table 5.

A study of Table 5 shows that the weight per gallon of the

TABLE 5.—RELATION BETWEEN SPECIFIC GRAVITY, THE BAUME HYDROMETER SCALE, AND THE WEIGHT PER GALLON

Specific gravity	Degrees Baume	Pounds per gallon	Specific gravity	Degrees Baume	Pounds per gallon
1.000	10	8.336	0.775	51	6.462
0.993	11	8.277	0.771	52	6.428
0.986	12	8.220	0.767	53	6.394
0.979	13	8.161	0.763	54	6.358
0.972	14	8.104	0.759	55	6.324
0.966	15	8.051	0.755	56	6.290
0.959	16	7.997	0.751	57	6.258
0.953	17	7.944	0.747	58	6.212
0.947	18	7.891	0.743	59	6.195
0.940	19	7.837	0.739	60	6.163
0.934	20	7.785	0.736	61	6.133
0.928	21	7.736	0.732	62	6.101
0.922	22	7.687	0.728	63	6.070
0.916	23	7.638	0.724	64	6.038
0.911	24	7.590	0.721	65	6,006
0.905	25	7.541	0.717	66	5.975
0.899	26	7.493	0.713	67	5.946
0.893	27	7.444	0.710	68	5.916
0.887	28	7.395	0.706	69	5.886
0.881	29	7.347	0.703	70	5.856
0.876	30	7.298	0.699	71	5.827
0.870	31	7.254	0.696	72	5.797
0.865	32	7.210	0.692	73	5.771
0.860	33	7.166	0.689	74	5.743
0.854	34	7.122	0.686	75	5.715
0.849	35	7.079	0.682	76	5.688
0.844	36	7.038	0.679	77	5.659
0.840	37	6.998	0.676	78	5.632
0.835	38	6.696	0.672	79	5.603
0.830	39	6.918	0.669	80	5.576
0.825	40	6.878	0.666	81	5.548
0.820	41	6.839	0.662	82	5.517
0.816	42	6.804	0.658	83	5.487
0.811	43	6.760	0.655	84	5.457
0.806	44	6.721	0.651	85	5.427
0.802	45	6.683	0.648	86	5.402
0.797	46	6.644	0.645	87	5.374
0.793	47	6.608	0.642	88	5.353
0.788	48	6.571	0.639	89	5.316
0.784	49	6.534	0.639	90	5.304
0.779	50	6.498			

heavier oil is greater than that of the lighter oils. Since the calorific value per pound of the various petroleum fuels is very nearly the same (see Table 4, Chapter III), and liquid fuels are bought by the gallon, it is evident that the total heat in a gallon of kerosene or in that of the still heavier oil, is much greater than the heat in a gallon of gasoline. Kerosene for farm use has the further advantages over gasoline in that it can be obtained everywhere, is cheaper, can be used for illumination in lamps and is not so dangerous.

Any good gasoline engine can be easily changed into one suitable for kerosene fuel. Such engines are started on gasoline and changed over to kerosene as soon as the cylinder walls become hot. Several types of engines, to be described later, will start on kerosene and will also operate on crude petroleum and on fuel oil. The first cost of such engines is greater than that of a gasoline engine, and these are used mainly in sizes of 25 h.p. and larger for the driving of pumps in irrigation plants, and also in connection with electric light plants for towns or cities.

The various types of gas tractors, to be described in another chapter, are usually started on gasoline and operate with kerosene or with solar oil, which is a heavier distillate than kerosene.

In general, an engine running on petroleum fuel other than gasoline is more difficult to start and requires greater care and more frequent cleaning of valves and pistons. For small engines gasoline has sufficient advantages to give it the preference to the cheaper petroleum fuels.

Alcohol as a Fuel for Gas-engine Use.—Alcohol as a fuel for gas-engine use has many advantages as compared with the petroleum distillates. It is less dangerous than gasoline, its products of combustion are odorless, and it lends itself to greater compression pressures than do the various petroleum fuels. Recent experiments by the United States Geological Survey and by others, show that the power of an ordinary gasoline engine can be increased by about 10 per cent. when using alcohol. Also that an engine designed to stand the compression pressures before ignition most suitable for alcohol will develop about 30 per cent. more power than a gasoline engine of the same size, stroke and speed.

Several years ago, when the internal revenue tax was removed from alcohol, so denatured as to destroy its character as a beverage, it was expected that denatured alcohol would become a very important fuel for use in gas engines. Its price up to this date, however, has been so much higher than that of gasoline, the most expensive of petroleum fuels, that its use in gas engines is out of the question. It is possible that, as the cost of the petroleum distillates increases, and processes are developed for producing denatured alcohol at a low price, the alcohol engine will come into prominence as a motor for farm use.

American denatured alcohol consists of 100 volumes of ethyl (grain) alcohol, mixed with ten volumes of methyl (wood) alcohol and with one-half a volume of benzol.

The specific gravity of denatured alcohol is about 0.795 and its calorific value is about two-thirds that of petroleum fuels. Alcohol requires less air for combustion than do petroleum fuels. Theoretically, the calorific value of a cubic foot of explosive mixtures of alcohol and of gasoline is about the same. Actual tests show that the fuel economy per horse-power is about the same for both fuels provided the compression pressures before ignition are best suited for the particular fuel used. In gasoline engines compression pressure of 75 lb. are used, while the alcohol engine gives best results, as far as economy and capacity are concerned, when the compression pressure before ignition is 180 lb. per square inch.

Essential Parts of a Gas Engine.—The essential parts of a gas engine are illustrated in Fig. 106. I and E are the valves which admit the mixture to and exhaust the mixture from the engine cylinder C. The reciprocating motion given to the piston B is communicated to the connecting rod D and is changed into rotary motion at the shaft F. The shaft F, while driving the machinery to which it is connected, also turns the valve gear shaft, sometimes called the two-to-one shaft, through the gears G and H. The gear H turns once for every two revolutions of the crank, and gives motion to the exhaust valve E through the rod L pivoted at R. In larger engines this valve gear shaft also opens and closes the admission valve and operates the fuel pump and ignition system. The spark for igniting the mixture is shown at O. As the temperatures resulting from the ignition of the explosion mixture is usually over 2000° F., some method of cooling the walls of the cylinder must be used in order to facilitate lubrication, to prevent the moving parts from being twisted out of shape and to avoid the ignition of the explosive mixture at the wrong time of the cycle. One method of cooling gas-engine cylinders is to jacket the cylinder and allow water to pass through the jacket space. In the engine illustrated in Fig. 106, the casting of the jacket is extended, so that it forms a box-shaped hopper M with a large opening at the top. The base U supports the various parts of the engine and the flywheel W carries the engine through the idle strokes. Besides the above details, every gas engine is usually provided with lubricators for the cylinder and bearings and with a governor for keeping the speed constant at variable loads.

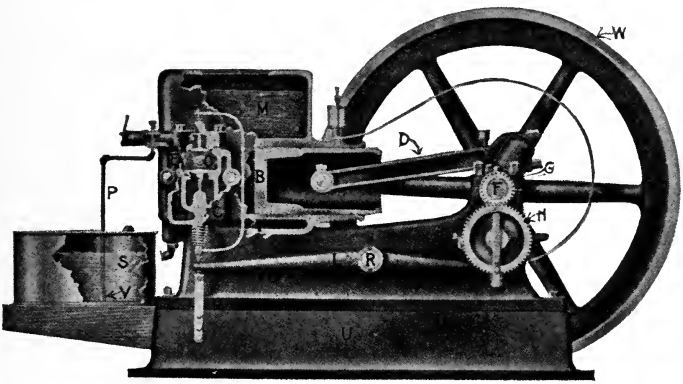


Fig. 106.

The engine shown in Fig. 106 uses gasoline as fuel, and is provided with a fuel tank S. A strainer V is placed at the end of the pipe P to protect the engine cylinder from any impurities which may be contained in the gasoline tank.

The various parts of vertical and horizontal gasoline engines are illustrated and named in Figs. 107 and 108.

Carbureters for Gasoline Engines.—The function of a carbureter is to vaporize the gasoline, mix it with the correct proportion of air to form an explosive mixture, and then deliver the mixture to the engine cylinder. A mixture of fuel and air in the proper proportions is one of the most important factors essential to the economical and safe operation of a gasoline engine. If the mixture has too little fuel, or is too lean, it will be slow burning. In fact it may still be burning when the inlet valve opens on the suction stroke and the flame flashing back through the inlet valve into the carbureter will produce what is called

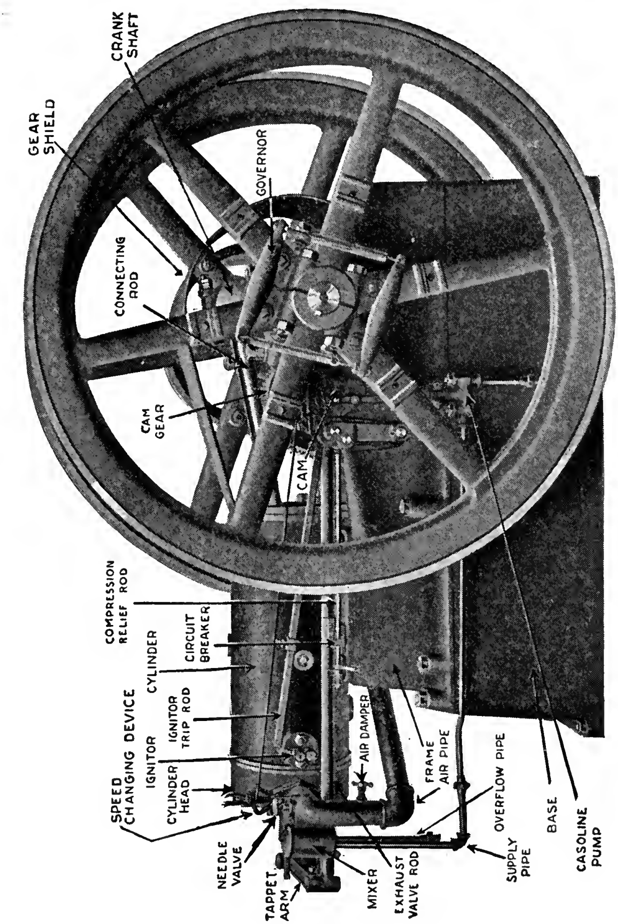


FIG. 107.

back-firing, and this may result in considerable damage to the engine. If the mixture is too rich, incomplete combustion will be produced with the consequent loss of power.

In some forms of carbureters the air is passed over the surface of the gasoline on its way to the engine and becomes saturated with the fuel. In another type, called the bubbling carbureter, the air is made to bubble through the fuel. The objection to these types of carbureters is that the air combines with only the more volatile portion of the fuel, leaving the heavier constituents not vaporized.

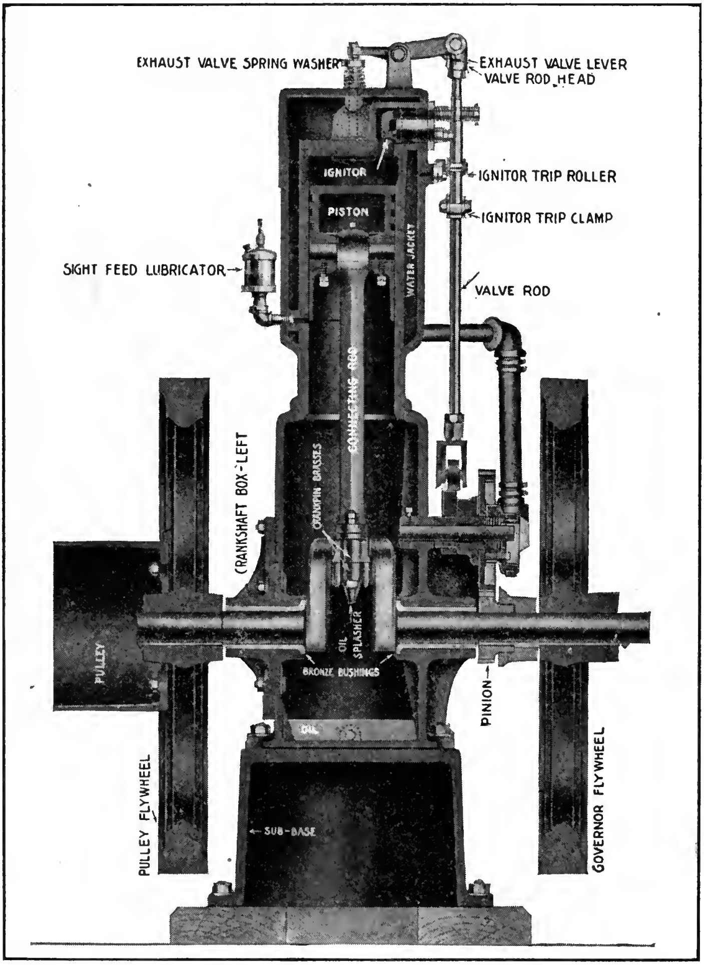


FIG. 108.

In the best forms of carbureters the gasoline is sprayed into the stream of air; this method utilizes the heavier portions as well as the more volatile vapors of the fuel.

In all spray carbureters the gasoline is delivered to a nozzle at constant pressure. In one type of carbureter, often called a mixer valve, this constant pressure is obtained by a pump keeping the height of the fuel at a uniform level in a small reservoir. The level of the fuel in the reservoir is maintained by an overflow pipe. This type of carbureter is well suited for stationary and semi-portable engines, and it is also used in some gasoline traction engines.

For automobiles, boats, portable engines and traction engines the float-feed type of carbureter is usually used. In the case of this carbureter the gasoline is admitted to a float chamber by gravity from a tank placed above the engine cylinder, the amount of fuel entering the chamber being regulated by a copper or cork float operating the gasoline valve. Most carbureters of the float-feed type are automatic in their action, in that the quality of the mixture is adjusted to suit the speed at which the motor is running.

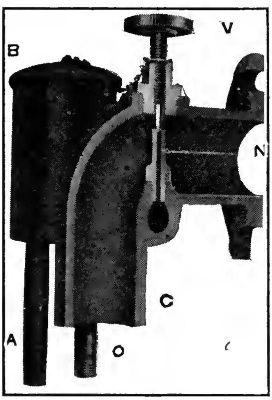


FIG. 109.

One form of mixer valve, or pump-feed carbureter, is illustrated in Fig. 109. A pump operated by the valve gear shaft of the engine forces the gasoline through the supply pipe A to the reservoir B. O is the overflow or return pipe which maintains the fuel at a constant level in the reservoir, and slightly below the point at which the needle valve V enters the gasoline nozzle N. When the piston of the engine starts on the suction stroke, a partial vacuum is created in the cylinder; the inlet valve is opened and a current of air is forced by the atmospheric pressure into the cylinder. This current of air enters through the air pipe C, attains a high velocity, and carries with it into the cylinder a portion of the gasoline vapor. This is the reason why the air passage of a carbureter is so arranged, that the velocity of the air is increased as it passes around the gasoline spray nozzle. The greater the velocity of the air at the nozzle the more vapor is carried into the engine cylinder. When starting an engine by hand with this form of carbureter, a damper or throttle in the air pipe is closed, so that the velocity of the air is increased sufficiently to admit the fuel to the cylinder. The relative positions of the air throttle and mixer are illustrated in Fig. 110.

Another form of mixer valve is illustrated in Fig. 111. Air enters at the lower opening C, gasoline flows in at 5 and the mixture of air and fuel leaves the mixer valve at B. The amount of gasoline fed is regulated by adjusting the needle valve at P.

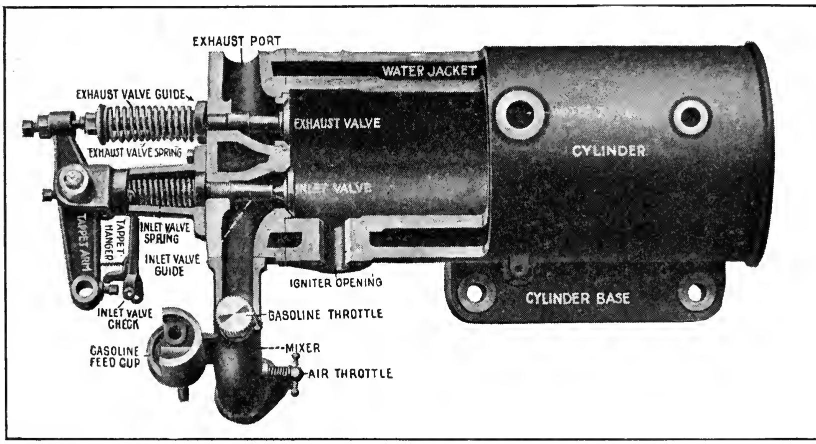


Fig. 110.

When the engine piston moves on its outward stroke the disc F is raised by suction, drawing in a charge of air through the seat opening and past the gasoline port into the mixing chamber above F. The lift and movement of the valve F, and consequently the quantity of the mixture to the cylinder, is regulated by the stem 6. The gasoline is supplied to the carbureter from a constant head reservoir in a manner similar to that described in connection with Fig. 109.

Automatic or float-feed carbureters are provided with two chambers, one a float chamber in which a constant level of the fuel is maintained by means of a float, the other a mixing chamber through which the air passes and mixes with the fuel. The float and mixing chambers may be placed side by side, or the two chambers may be constructed concentric.

A float-feed carbureter with the two chambers side by side is illustrated in Fig. 112. In the float chamber is placed a float made either of cork or of metal. The hollow metal float is more expensive and is liable to leak. Cork floats when covered thoroughly with shellac will not lose their buoyancy, but there is some danger that particles may become detached from the cork and clog the passages leading to the spray nozzle. When the

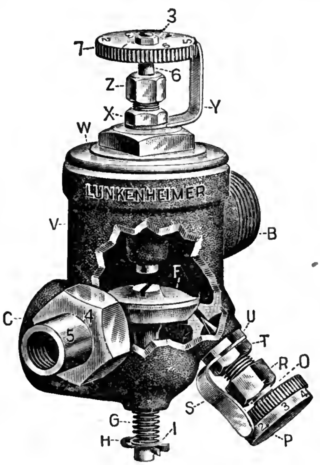


FIG. 111.—Lunkenheimer mixer valve.

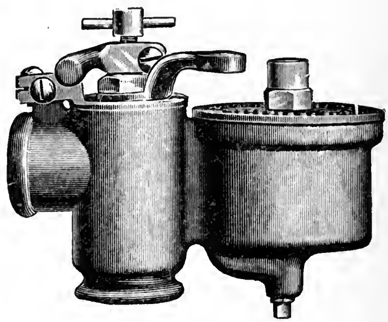


FIG. 112.

float chamber becomes filled with gasoline to a certain level, the float lifts a ball or a needle valve, and the flow of fuel is stopped. The fuel from the float chamber enters the mixing chamber at the left, is picked up by the air coming at high velocity, and the mixture passes to the engine cylinder.

A concentric float-feed type of carbureter is illustrated in Fig. 113. K represents the float, which operates the float valve V and regulates the amount of gasoline entering the float chamber W through fuel inlet at G. The air inlet to the carbureter is at D. A is the gasoline adjusting screw which regulates the needle valve. The passage of the mixing chamber around the top of the spraying nozzle J is constructed so as to increase the velocity of the air at that point. This part is called the throat or Venturi tube of the carbureter. The amount of mixture which is allowed to pass through the gas outlet C to the engine cylinder is regulated by the throttle E. As the throttle E is opened and the speed of the motor increases, the velocity of the air at the Venturi passage becomes great and too much fuel is pulled in by the air. To overcome this, the latest carbureters are arranged with auxiliary valves which are controlled by the balls M. These auxiliary valves admit more air as the speed of the motor increases and the mixture is diluted before it is allowed to enter the engine cylinder.

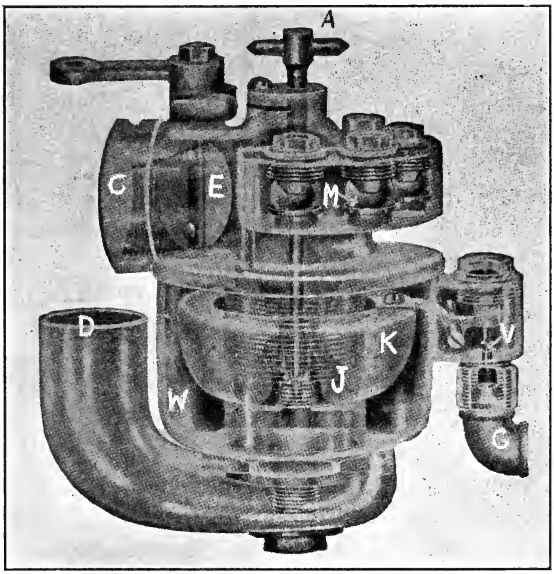


FIG. 113.

Most float-feed carbureters are provided with some hand-operated method for priming the carbureter. This is accomplished by depressing the float, so that an excess of gasoline may be allowed to enter the mixing chamber.

Carbureting Kerosene and the Heavier Fuels.—The various forms of carbureters described cannot be used for kerosene or for the heavier petroleum fuels, as these fuels are less volatile than gasoline at ordinary temperatures and pressures. The heavier the fuel the more heat is required to vaporize it.

An ordinary gasoline engine will operate with kerosene fuel, if started on gasoline, but carbon deposits in the cylinder will necessitate frequent cleaning of the cylinder walls, piston and rings.

Some engines work very successfully with kerosene and solar oil, if the fuel is vaporized by the exhaust gases in a coil located entirely outside of the engine cylinder. It has been found that the injection of water with the fuel reduces the carbon deposits in the cylinder and improves the operation of the engine.

Oil engines for burning fuels heavier than 40° Baume have been perfected. These engines are either of the Diesel or semi-Diesel types, and ignite the fuel automatically. The principle of construction of engines for heavy fuels will be explained in the section on "ignition."

Cooling of Gas-engine Cylinder Walls.—The necessity for cooling gas-engine cylinder walls was explained in an earlier part of this chapter. In smaller engines only the cylinder or cylinder and cylinder head must be cooled. In large engines it becomes necessary to cool also the piston and exhaust valve.

Three methods are used for cooling gas engines:

1. Air cooling.
2. Water cooling.
3. Oil cooling.

An air-cooled gasoline engine is illustrated in Figs. 114 and 115. The cylinder is cast with webs, and air is forced by means of a fan driven from the engine. In very small engines natural air circulation is used. The air-cooling system has not been found practical for engines above 5 h.p. Even for small engines there is no positive temperature control with this system of cooling. This often results in the decomposition of the cylinder oil and in carbon deposits on the piston and cylinder walls.

Cooling of cylinder walls by means of water is the most common method. In this case the cylinder barrel or the cylinder barrel and cylinder head are jacketed, that is they are built with double walls and water is circulated through the space between the walls. One method of water cooling was illustrated in connection with the hopper-cooled engine in Fig. 106. In this case the water is heated by contact with the hot cylinder walls, rises and is replaced by cooler water.

Another system of water cooling is to place a galvanized iron tank filled with water near the e gine and connect the lower part of the cylinder jacket to the bottom of the tank and the upper part of the jacket at the top of the tank. The cold water enters the jacket at the bottom, is heated, rises and flows to the upper part of the tank, the water circulation being similar to that of the hopper-cooled engine.

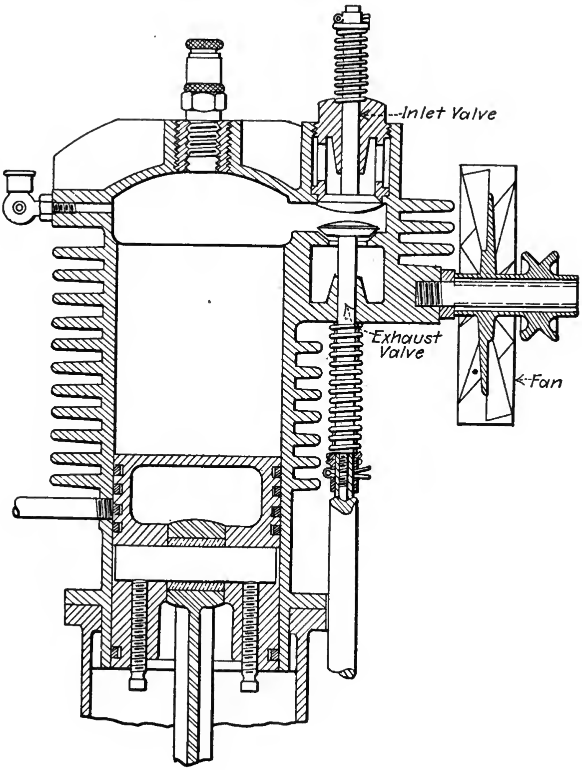


Fig. 114.

In order to definitely control the temperature of the water jacket, the forced system of water circulation shown in Fig. 116 is preferable to the two described. This system is used when a constant source of water supply is available. The temperature in the jacket is usually maintained at about 150°.

Another method of water cooling by forced circulation, used quite extensively on small stationary and portable engines, is illustrated in Fig. 117. The water from the lower part of the tank T is forced by a pump through the jacket. The water enters the bottom of the jacket, and leaves from the top of the jacket by the pipe P. The water is then allowed to pass over the screen S and is cooled by evaporation before reentering the tank. The advantage of this system is that the screen acts as a

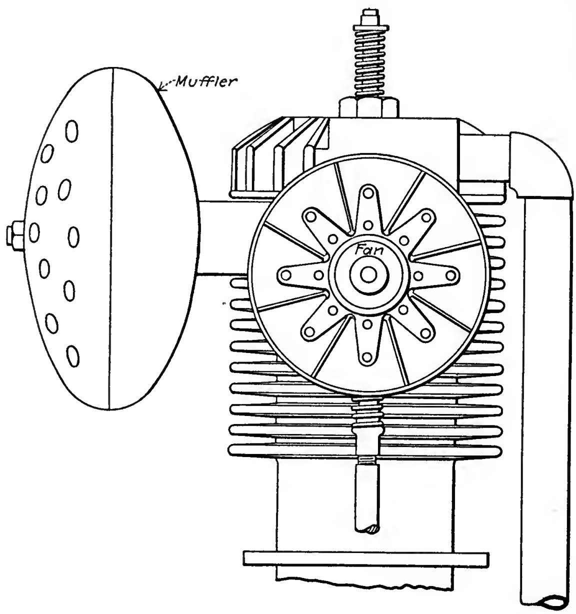


Fig. 115.

cooling tower and reduces the weight of water which must be carried with the engine.

Oil is being used for cooling gas-engine cylinders to a limited extent where the engines are exposed to low temperatures. The systems of oil cooling are similar to water cooling. In some cases natural circulation is employed, using hoppers or tanks, while in other types some form of forced cooling like the one illustrated in Fig. 117 is used. However, oil is not a satisfactory cooling medium on account of its inability to take up heat as easily as water.

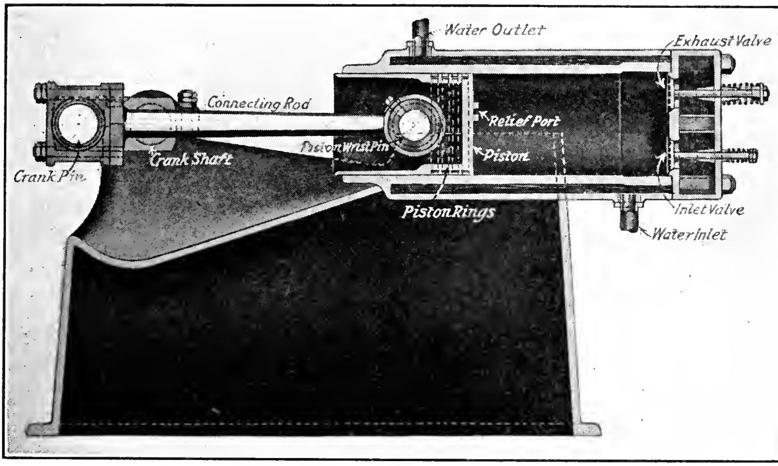


FIG. 116.

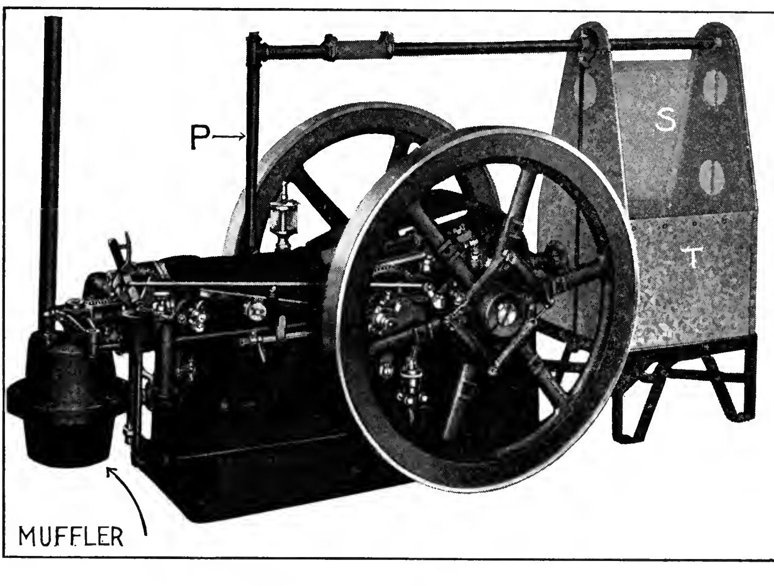


FIG. 117.

In some cases non-freezing mixtures composed of wood alcohol and glycerine have been used for cooling the cylinders of gas engines. Calcium chloride and common salt have also been used to some extent for the cooling of engines. These mixtures will tend to prevent freezing and the consequent cracking of the jacket and cylinder walls during cold weather when the engine is not running.

When water is the cooling medium, the engine should be provided with a drain cock at the lowest point of the jacket, so that the jacket can be thoroughly drained in freezing weather.

Gas-engine Ignition Systems.—Ignition in all modern gas engines is accomplished either by an electric spark, or automatically by the high compression to which either the air or the mixture is subjected in the engine cylinder.

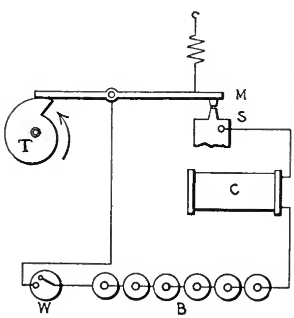


FIG. 118.

In some older makes of engines the hot tube system of ignition is still employed, in which a tube, made of porcelain or of some nickel alloy, is open at one end to the cylinder and is closed at the other. The closed end of the tube is heated by a Bunsen burner. A portion of the explosive mixture is forced into the tube during the compression stroke of the piston, and is fired by the heat of the tube walls. Accurate timing of the point of ignition is quite impossible with the hot tube system. The only points in favor of this system are the low first cost and cost of maintenance as compared with the electric system.

Electric Ignition Systems for Gas Engines.—There are two systems of electric ignition:

1. The make and break.
2. The jump spark.

A student not familiar with the fundamentals of electricity will do well to study Chapter X before taking up electric ignition.

The principle of the make-and-break system is illustrated in Fig. 118. B is a battery which supplies the electric current for ignition. C is an inductive spark coil, often called a kick coil. It consists of a bundle of soft iron wires surrounded by a coil of insulated copper wire through which the current passes. On account of the inductive action of such a coil, the spark is greatly intensified. S is a stationary electrode well insulated from the engine and M is a movable electrode not insulated from the engine. The contact points of the two electrodes are brought together by means of a cam T operated from the valve gear shaft of the engine. When the switch W is closed, current will flow through the circuit as soon as the contact points of the electrodes are brought together by the cam T. A

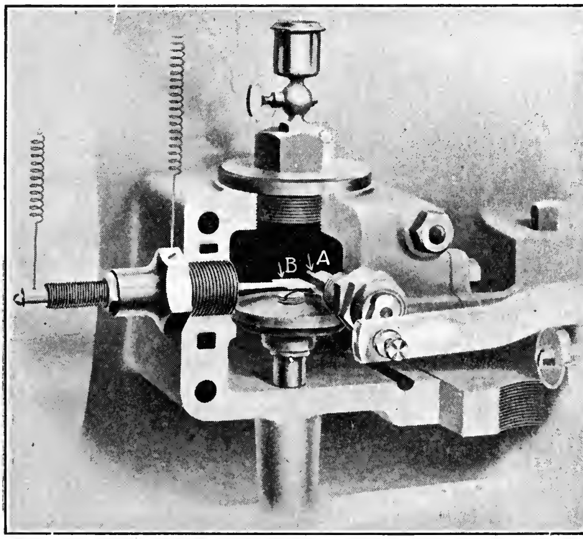


FIG. 119.

sudden breaking of the contact, aided by a spring, causes a spark to pass between the points which ignites the mixture.

The contact between the two electrodes of the make-and-break system can be made by sliding one contact point over the other, this being known as the wipe-spark igniter and is illustrated in Fig. 119. A is the movable and B is the stationary electrode. Another type shown in Fig. 120 is called the hammer break igniter. S is the stationary and M is the movable electrode. The interrupter lever I is operated from a cam on the valve gear shaft until the two contact points M and S are brought in contact. At the desired time, I is tripped and flies back, instantly breaking the contact and producing an arc between M and S. Another form of hammer make and break igniter is illustrated in Fig. 121.

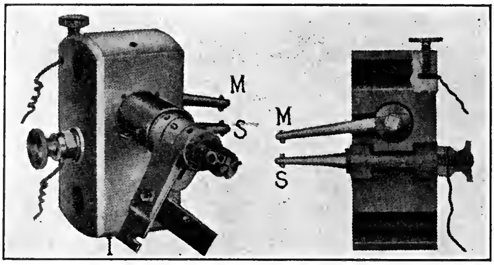


FIG. 120.

Wipe spark igniters keep the contact points cleaner than hammer break types. The hammer break igniter is more commonly used on account of the easier adjustment and less wear of the contact points.

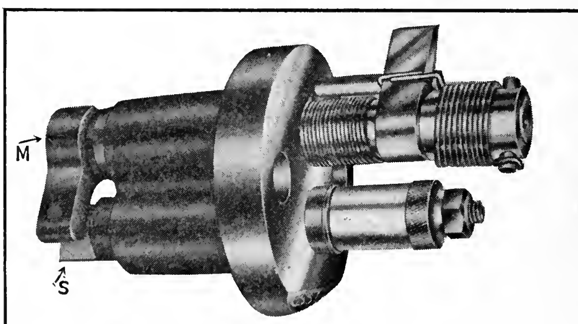


FIG. 121.

The principle of the jump-spark system is illustrated in Fig. 122. A is a spark plug, the spark points E and F of which project into the cylinder. These spark points are stationary, insulated from each other, and separated by an air gap of about 1/16 in. When the switch W is closed the current from the battery B flows through the timer T, which completes the circuit at the proper time through the induction coil I, and the induced current produces a spark at the spark plug gap, igniting the explosive mixture in the cylinder.

The method of wiring batteries, coil, timer and spark plug is well illustrated in Fig. 123.

The induction coil I, Fig. 122, differs from the inductance coil used in connection with the make-and-break system of ignition, in that two layers of insulated wire are wound on the core of the induction coil and only one layer in the case of the inductance coil. One of the layers, called the primary, consists of several turns of fairly large insulated copper wire. The other winding is a coil of many turns of very fine insulated wire and has no

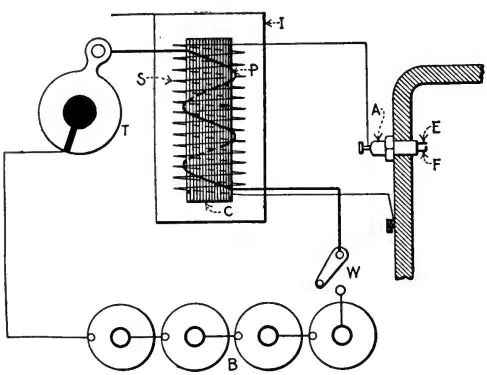


FIG. 122.

metallic contact with the primary. In Fig. 122, P represents the primary, S the secondary, and C the core, which consists of a bundle of soft iron wire. The current from the battery B (Fig. 122) enters the primary winding of the induction coil P and induces a high-voltage current in the secondary winding S. This high-voltage current is sufficiently powerful to produce a spark in the air gap of the spark plug A.

An induction coil is shown in Fig. 124. This coil differs from the one described (Fig. 122) by the addition of a vibrator, trembler or interrupter R. The function of this vibrator is to interrupt the primary circuit with great rapidity; this action induces an alternating current in the secondary and a series of sparks at the air gap of the spark coil.

All induction coils are also provided with an electric condenser, which consists of alternate layers of tin-foil and some

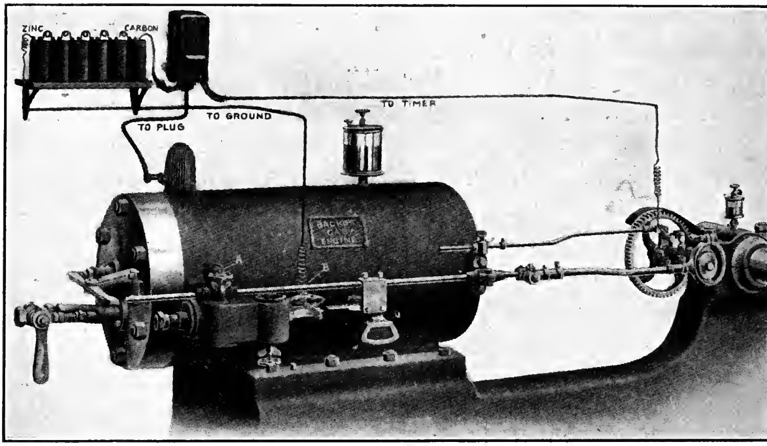


FIG. 123.

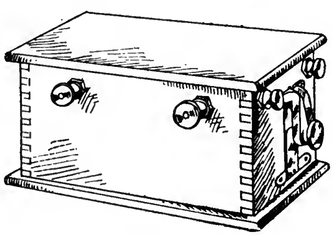


FIG. 124.

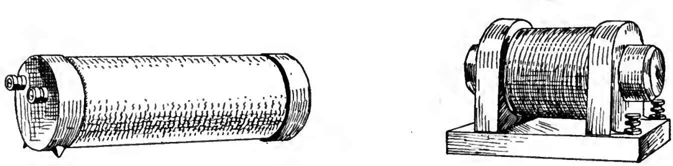


FIG. 125.

insulating material like paraffined paper. The condenser acts like an air chamber of a pump, in that it absorbs the excess of current at the primary winding, prevents sparking at the vibrator and gives out this excess at the proper time to increase the intensity of the spark.

An inductance coil suitable for the make-and-break system of ignition is shown in Fig. 125.

A spark plug used in connection with the jump-spark system of ignition is illustrated in Fig. 126. It consists essentially of two platinum wire points, well insulated from each other. The central point is connected to the binding post which receives current from the secondary, or high-tension winding of the induction coil. The other point is not insulated from the thread, and completes the circuit when the spark plug is in the engine cylinder.

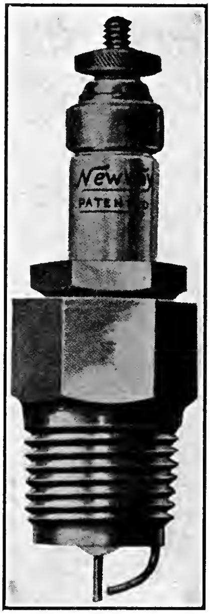


Fig. 126.

Comparing the two systems of electric ignition, the jump-spark system is much more simple mechanically as it has no moving parts inside the cylinder. The make-and-break system is simpler electrically, does not have to be insulated so carefully and the spark is more certain. The make-and-break system is usually used on stationary engines and to some extent on traction engines. The jump-spark system is better adapted for high-speed engines than is the make-and-break, and is used on automobiles, small stationary engines, marine engines and also on traction engines.

In regard to the sources of electricity for ignition, this may be derived from an ordinary lighting circuit, from a primary cell, from a storage battery, or from some form of small ignition dynamo or magneto.

The primary and storage batteries are fully explained in Chapter X.

An ignition dynamo is a miniature direct-current dynamo, built on the same plan as any large dynamo used for lighting. It has electromagnets as field magnets and is usually of the iron-clad type. One form of ignition dynamo is shown in Fig. 127. In using an ignition dynamo the engine must be started on batteries, as the speed developed when turning the engine by hand is insufficient to produce a spark of sufficient in-

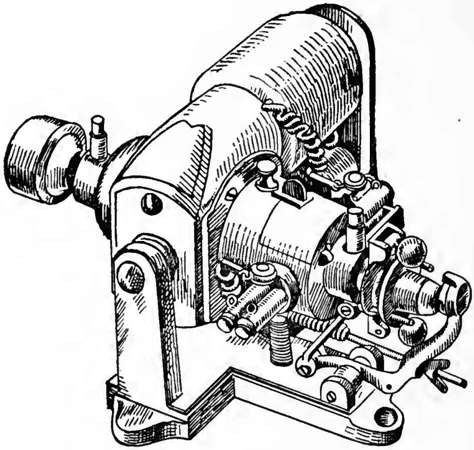
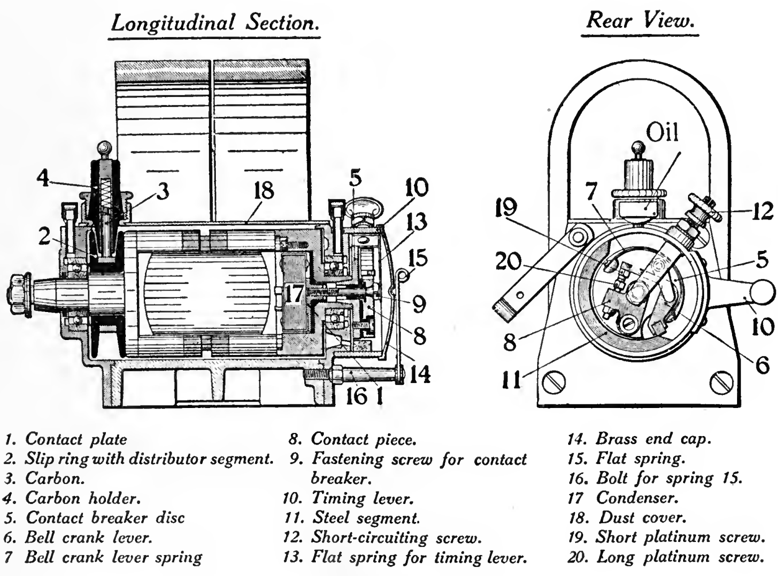


Fig. 127.

Fig. 128.

tensity by the dynamo. As soon as the engine speeds up, the battery current is thrown off and the spark is supplied by the ignition dynamo. Most ignition dynamos will supply a spark of sufficient intensity for a make-and-break system of ignition without an inductance coil. For jump-spark ignition a special induction coil must be used with the ignition dynamo.

The magneto differs from the ignition dynamo in that its fields are permanent magnets instead of electromagnets. For this reason the magneto may be run in either direction and at any desired speed. Magnetos should always be positively driven from the engine, as there must be a definite relation between the time the spark is produced by the magneto and the position of the crank shaft.



1. Contact plate
2. Slip ring with distributor segment.
3. Carbon.
4. Carbon holder.
5. Contact breaker disc
6. Bell crank lever.
7 Bell crank lever spring
8. Contact piece.
9. Fastening screw for contact breaker.
10. Timing lever.
11. Steel segment.
12. Short-circuiting screw.
13. Flat spring for timing lever.
14. Brass end cap.
15. Flat spring.
16. Bolt for spring 15.
17 Condenser.
18. Dust cover.
19. Short platinum screw.
20. Long platinum screw.

FIG. 129.

Magnetos are of two types:

1. The low-tension magneto shown in Fig. 128 is used instead of a battery and inductance coil for make-and-break systems of ignition.

2. The high-tension magneto (Fig. 129) is used for jump-spark systems of ignition. It differs from the low-tension magneto, in that the armature is provided with two windings, a primary and a secondary, and also includes a condenser. The

high-tension magneto takes the place of the battery, induction coil and condenser for the jump-spark system.

Automatic Ignition for Oil Engines.—One type of oil engine, the Hornsby Akroyd, is illustrated in Fig. 130. The engine is provided with an unjacketed vaporizer A, which communicates with the cylinder by means of the small opening B. This vaporizer is raised to a red heat, before starting by means of a torch, and is kept hot by repeated explosions when the engine is running. This engine works on the regular four-stroke Otto gas engine cycle. During the suction stroke of the piston only air is sucked

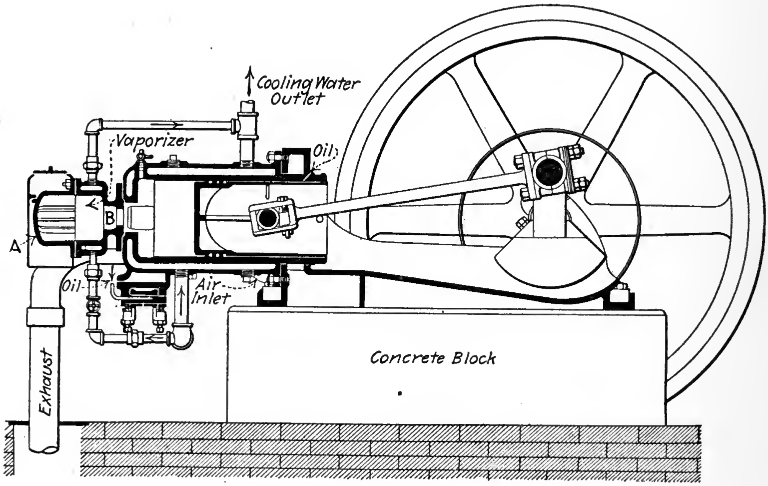


Fig. 130.

into the cylinder and the charge of oil fuel is injected into the vaporizer by a pump. On the return stroke the air is compressed, forced in the vaporizer, mixed with the fuel and automatically ignited. This is followed by the expansion and exhaust strokes, as in other internal combustion engines.

A modification of this type of engine is the so-called semi-Diesel type of oil engine, which is well adapted for the burning of the lowest grades of petroleum fuels. In this case the air is compressed to about 250 lb. per square inch before the fuel is injected into the cylinder.

The Diesel engine was mentioned in the first part of this chapter. It is very economical for the burning of low grades of fuel, but the high first cost of the engine limits its field of application.

Governing of Gas Engines.—Every gas engine must be provided with some governing mechanism in order that its speed may be kept constant as the power developed by the engine varies. The governing mechanism is operated by the speed variations of the engine and the speed control is accomplished by the following methods.

1. Hit-or-miss Governing. In this system the number of explosions is varied according to the load on the engine. This can be carried out in several ways, depending on the valve gear of the engine.

In the case of small engines, where the inlet valve is automatically operated by the vacuum created in the cylinder during the suction stroke, the governor operates on the exhaust valve by holding it open during the suction stroke. The free communication of the engine cylinder with the outside prevents the formation of sufficient vacuum in the cylinder to lift the inlet valve.

When the inlet valve is mechanically operated from the valve gear shaft, the governor acts on the inlet valve keeping it closed part of the time at light loads. The governor used to accomplish this is usually some form of flyball governor. As the speed of the engine increases, the balls are thrown out by centrifugal force and shift the position of a cam on the valve gear shaft preventing the opening of the inlet valve.

The hit-or-miss system of governing can also be carried out by having the governor open a switch, thus interrupting the flow of current to the igniter, as the load decreases. This method is very wasteful of fuel as the fuel drawn in at each suction stroke passes through the engine and is wasted. It should be used only in connection with one of the other methods of governing.

The hit-or-miss system of governing is very simple and gives good fuel economy at variable loads. As the explosions in the engine do not occur at regular intervals, this system of governing necessitates the use of very heavy flywheels in order to keep the speed fluctuations within practical limits. The hit-or-miss system is very well adapted for small and also for medium size engines where very close speed regulation is not essential.

2. Varying Quantity of Mixture.—In this system the proportion of air to fuel is kept constant and the quantity of the mixture admitted into the cylinder is varied according to the load. This variation is accomplished either by throttling the charge or by changing the time during which the inlet valve is open to the cylinder. In fact the two methods of varying the quantity of the mixture are similar to those used in governing steam engines and as explained in Chapter V.

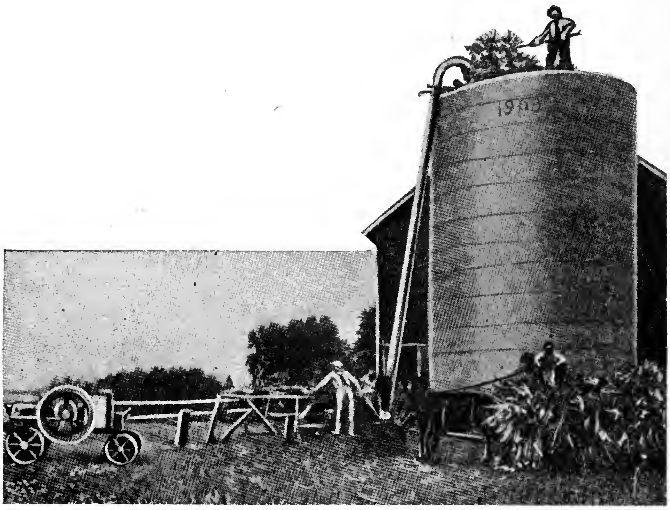


FIG. 131.

3. Varying Quality of Mixture.—In this case the total quantity admitted into the cylinder is kept constant, but the amount of fuel mixed with the air is varied according to the load.

When gas engines are governed by varying the quantity or quality of the mixture, the speed is more uniform at variable loads. Also since the explosions occur at definite periods, the temperatures inside of the cylinder, are kept more constant. The throttling form of governor is used most commonly with traction engines.

The Gasoline Engine on the Farm.—Some of the uses to which a gasoline engine can be applied on the farm are illustrated in Figs. 131 to 141.

A 12-h.p. gasoline engine is shown driving an ensilage cutter and silo filler in Fig. 131.

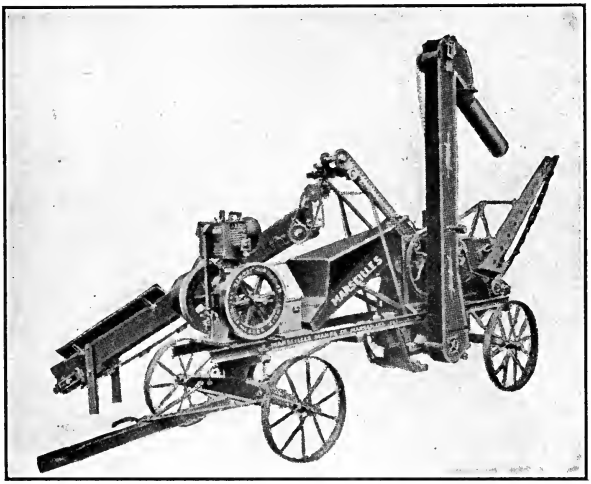


FIG. 132.

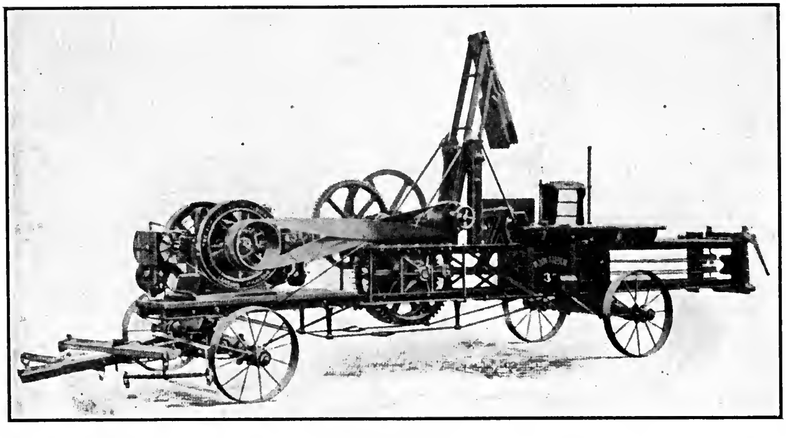


FIG. 133.

Another engine of 3 1/2 h.p. drives a corn sheller, Fig. 132. A 7-h.p. engine is illustrated in Fig. 133 driving a hay press.

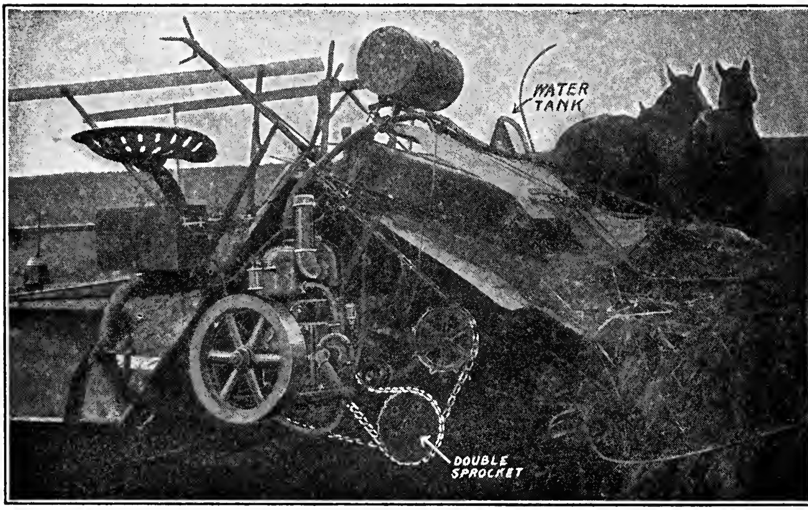


FIG. 134.

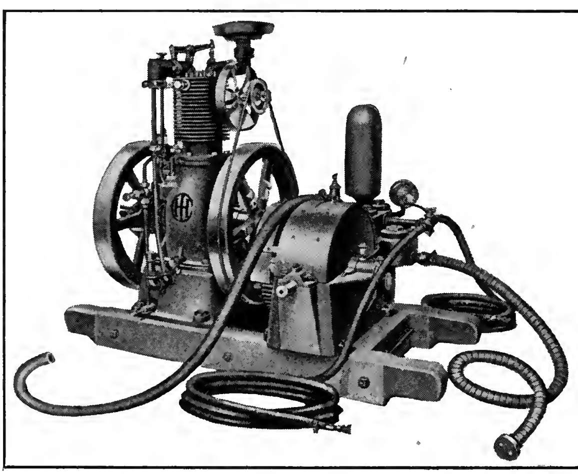


FIG. 135.

A binder driven by a 4-h.p. engine is shown in Fig. 134.

An air-cooled gasoline engine of 2 h.p., direct-connected to a spraying outfit (Fig. 135), is capable of producing a pressure of 100 lb. per square inch or more, as compared with about 50 lb. in the case of the hand sprayer.

Fig. 136.

The application of the gasoline engine to pumping water for household use and for irrigation is illustrated in Figs. 136 and 137.

Figures 138, 139 and 140 show the application of the small gasoline engine for the driving of cream separators, churns and washing machines.

A wood-sawing rig, Fig. 141, can be removed by loosening clamp bolts, and the engine used for grinding feed, pumping, shredding or for any other farm work within its capacity.

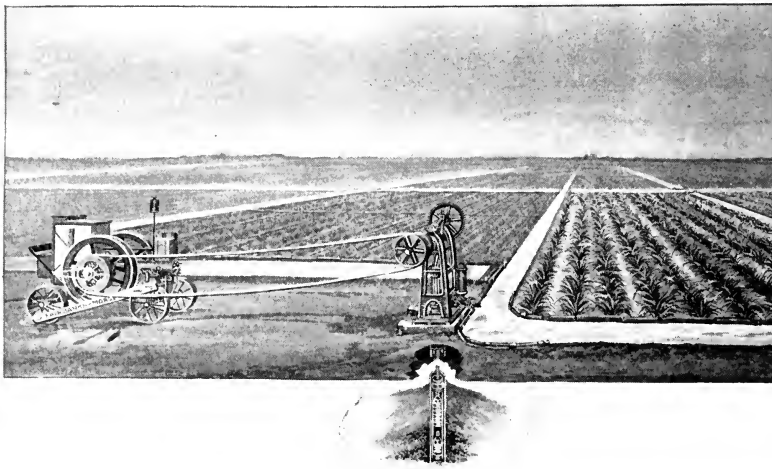


FIG. 137.

Other uses to which the gasoline engine can be put include: the driving of cement mixers, and rock crushers, the grinding of

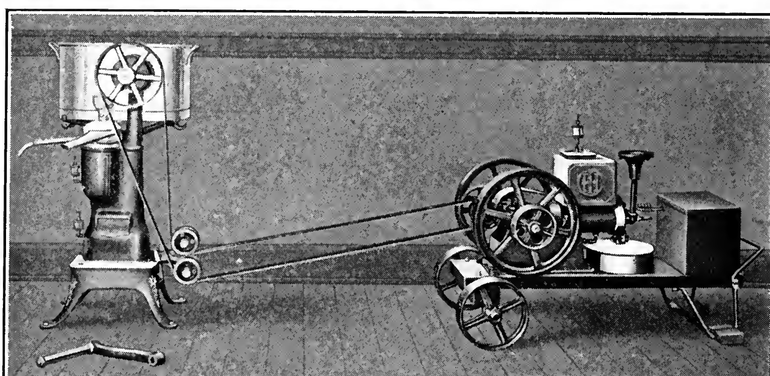


FIG. 138.

feed, the driving of grindstones and other tools in the farm shop, the driving of electric generators for farm lighting (see Chapter

X), and for various other work about the house, barn and dairy which require power.

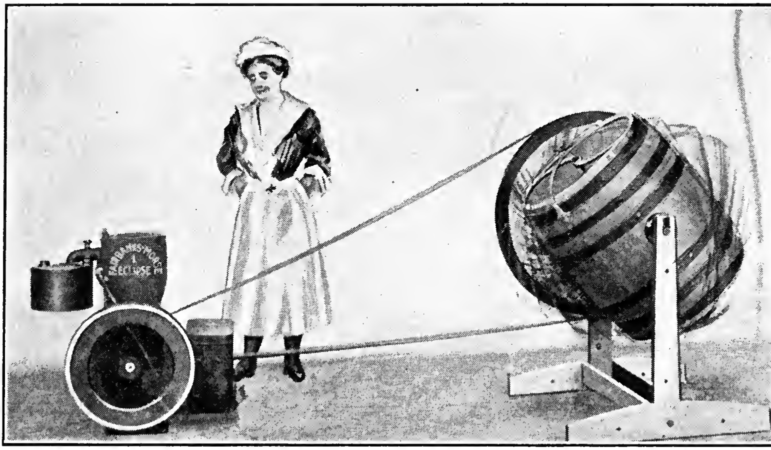


FIG. 139.

FIG. 140.

Gas tractors and their field of application will be taken up in Chapter VII.

Selection and Management of Gas and Oil Engines

Selecting a Gas Engine.—A gas engine should be selected large enough to do the required work, as it will stand but little overload. This is due to the fact that the gas engine develops its maximum power, when a full charge of the best mixture of fuel and air, at the maximum density, has been admitted to the engine cylinder. On the other hand, an engine too large for the work it has to do will give poor fuel economy.

As the economy is very nearly independent of the size of the gas engine, it is better to buy two small engines than one large one. This applies especially to the farm, where the larger engine of 6 to 10 h.p. can be used for the heavier work such as feed grinding, threshing, wood sawing, etc., and a small engine of about 2 h.p. for the many small tasks, about the house, dairy

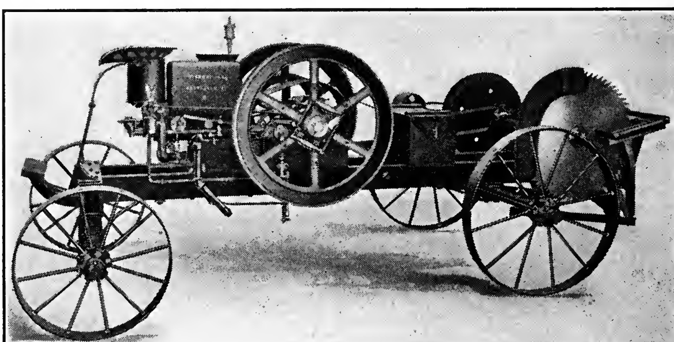


Fig. 141.

and barn, which require but little power. An engine of 2 h.p. is sufficient to drive a small dynamo, light the house, barn, etc., and charge a storage battery (see Chapter X). The same engine, if portable, can be used for driving a washing machine and wringer, a tree sprayer outfit, a house pump, cream separator, etc.

An engine governed by the hit-or-miss principle should carry such a load as will enable it to miss one explosion in every eight, as this will keep the cylinder free from inert burned gases and will improve the economy. If an engine is worked at its maximum power the largest part of the time the wear on the parts will be too great.

An engine for farm use must be capable of being started easily and should be simple in construction. Every gas engine must have certain parts to carry out the cycle of operations, as explained in the earlier part of this chapter, but some engines are provided with many attachments, which have good points, but complicate the engine so that the first cost is greater and the manipulation more difficult. An engine to be of value on the farm must be sufficiently simple in construction so that ordinary adjustments and repairs can be made without the aid of experts.

In regard to the method of igniting the mixture, the electric system is best for gasoline engines. It is well to provide a gasoline engine with a magneto or ingition dynamo, as with batteries the cost of upkeep is considerable and the reliability of operation uncertain. Regarding drives for magnetos, friction and belt drives should not be selected, as they are not reliable. A magneto should always be positively driven from the engine by gears.

There is very little choice between the jump-spark and the make-and-break systems of ignition. For stationary engines the make-and-break is commonly used while the jump-spark is more common on automobiles and traction engines. No matter which system of electric ignition is selected, the various wires should be well insulated, and enclosed in some moisture-proof conduit.

For irrigation work where the cost of fuel is an important item, an engine should be selected which will operate with the cheaper fuels. For engines under 100 h.p., those which will burn solar oil will usually be found satisfactory. Such engines employ electric ignition and the fuel is vaporized in a coil entirely outside of the engine cylinder. For work requiring 100 h.p. and more the various engines with automatic ignition, which use the very heavy oils, will be found more economical.

It is essential to select an engine from a reputable manufacturer Every engine has parts broken and it is important that duplicate parts may be easily secured. It is also well to investigate the work done by engines of various makes before making the final selection.

The rated horse-power of an engine does not often mean the same actual power for different makes of engines. An engine rated at 10 h.p. by one manufacturer may be capable of developing 10 to 25 per cent. more power than an engine of the same rating by another manufacturer. The purchaser should insist on a definite statement as to the actual brake horse-power which the engine is capable of developing. The method of obtaining the brake horse-power of an engine was explained in Chapter II.

Installation of Gas Engines.—It is usually best to locate a gas engine in a separate room. The room should be well lighted and ventilated, free from dirt and dust and should be large enough so that there would be sufficient space for easy access to any part of the engine so as to facilitate starting, oiling and inspection of all parts.

In connection with gasoline and oil engines, the fuel tank should be located outside of the building and preferably underground. In any case the tank must be lower than the pipe to which it is connected in the engine room.

As the mixture of fuel and air is ignited inside the engine cylinder, the resulting explosion produces a shock of considerable magnitude on the mechanism, which in turn is transmitted to the foundation. The foundation should be as solid as possible. If the engine is to be set on a wood floor, it is usually well to lay long timbers on or under the floor and at right angles to the joists. If the foundation is to be built of brick or of concrete it should be sufficiently heavy and should be separated from the walls of the building, so that vibrations caused by the engine will not affect the building or surrounding buildings. If the engine has to be located over another room it is best to place the engine in a corner and near the wall.

The method of constructing foundations for steam engines was explained in detail in Chapter V. The directions given there apply also to gas engines.

If the engine is to be connected to the machines to be driven by belt drive, the driver and driven should be placed far enough apart, so that the required power can be transmitted without running the belts too tight. A distance between pulleys equal to about eight times the size of the larger pulley will usually give good results. Open belts are preferable to crossed belts and should be used whenever possible.

The exhaust piping should be as straight and as short as possible. The exhaust gases should always be discharged out of doors, as the fumes are poisonous. Some engines are provided with exhaust mufflers (Fig. 117) which can be located near the engine. As a rule it is better to locate the muffler outside of the building. Engines should never exhaust into a flue or chimney.

The air supply can be taken from the room in which the engine is placed or from the outside. In all cases a screen should be placed over the air pipe.

Instructions for Starting Gas Engines.—Before an engine is started for the first time, all the working parts should be carefully examined and nuts and other fasteners properly tightened. The electrical connections should then be gone over and the spark plug or spark points removed from the cylinder and tried. The various valves should then be set to operate at the proper time. The inlet valve should open just before the piston starts on its suction stroke. The exhaust valve should open when the piston is very near the end of the expansion stroke and should remain open until the crank is about 10 degrees before the completion of the exhaust stroke. The ignition should be timed so that the spark occurs at a crank position of about 15 degrees before the end of the compression stroke.

The gas engine is not self starting, as is the steam engine when steam is turned on. The reason for this is that the explosive mixture of fuel and air must be taken into the cylinder and compressed before it can give up its energy by explosion. It is, therefore, necessary to set the engine in motion by some external means not employed in regular operation, before it will pick up the normal working cycle. Engines under 20 h.p. are usually started by hand. This is done by disconnecting the engine from its load and turning the fiywheel by hand for a few revolutions. If everything is in good condition an engine should start with two or three turns of the flywheel and should continue to run after the first explosion. An easier method of starting gasoline engines is by injecting some gasoline into the cylinder through a priming cock, turning the flywheel against compression as far as possible and then quickly tripping the igniter.

As it is difficult to pull over an engine by hand against compression throughout the whole stroke, most engines are provided with a starting cam, which can be shifted so as to engage the exhaust valve lever. This relieves the compression while cranking, as the exhaust port is open during the first part of the compression stroke. After the engine speeds up the starting cam is disengaged.

Gas engines larger than 25 h.p. are usually started with compressed air. If the engine consists of two or more cylinders, this can be accomplished by shutting off the gas supply to one of the cylinders and running this cylinder with compressed air from a tank, in the same manner as a steam engine is operated with steam from a boiler. As soon as the other cylinders pick up their cycle of operations the compressed air is shut off and fuel with air is admitted to the cylinder used in starting. With large gas engines of only one cylinder, the compressed air is admitted long enough to start the engine revolving, when the compressed air is shut off and the mixture is admitted. The air supply for starting is kept in tanks which are charged to a pressure of 50 to 150 lb. by a small compressor, driven either from the main engine shaft, or by means of an auxiliary small engine.

In starting a gas engine the following steps should be taken, preferably in the order given:

1. The fuel supply should be examined. Cases have been known in which an operator spent considerable time hunting for faults in the ignition system, valve setting, etc., when an examination of the gasoline tank would have revealed the fact that it was empty.

2. The ignition system should be tried by closing the switch disconnecting the end of one of the wires and brushing it against the binding post to which the other wire is attached. A good spark should have a blue white color. If the spark produced is weak the ignition system should be put in the proper condition.

3. The lubricators and grease cups should be filled and adjusted, so that the proper amount of oil is delivered to all bearings and moving parts.

4. The load should be disconnected from the engine by means of a friction clutch or similar device, the lubricators turned on, the spark retarded to the starting position, and the starting cam moved in place.

5. The engine is now ready for starting by either of the methods previously explained. In cranking, always pull up on the crank.

6. As soon as engine picks up, disengage starting cam, turn on cooling water, advance spark to running position and throw on the load by means of the clutch.

7. Adjust fuel supply so that the engine carries its load with the cleanest possible exhaust.

To stop an engine, the fuel valve is closed, the ignition system switch opened, the lubricators and oil cups are closed and the jacket water is turned off. In cold weather the water should be drained from the engine jackets to prevent freezing. The practice of draining the jackets is also advisable in moderate weather as this tends to clean the jacket from the deposit of sediment. Before leaving the engine it should be cleaned, all parts examined and put in order ready for starting up.

Causes of Gas Engines Failing to Start.—Failure to start may be due to one or more of the following causes:

1. *Ignition System Out of Order.*—This may be caused by the switch being left open, by a loose terminal, by a disconnected wire, by a broken wire the insulation being intact, by the ignition battery being weak if a battery is used, and by poor timing or wrong connections if a magneto is employed. Other causes of faulty ignition are due to timer slipping on the shaft, to a short circuit in the ignition system, to carbonized or broken spark points, to poor timing of the points of ignition. In the case of the jump spark system, ignition will also be prevented if the points on the spark plug are too far apart, the insulation on secondary wires is poor, induction coil windings are broken or short-circuited, vibrator of induction coil not properly set.

2. An engine will not start if the mixture contains too much or too little fuel.

In very cold weather a gasoline engine may give trouble by the fuel not vaporizing. This can best be remedied by filling the jackets with hot water.

Improper mixture may be caused by slow cranking, in which case the hand placed over the air inlet will often start the engine. Extra priming of the carbureter may also aid in starting, provided care is taken not to flood the engine with fuel.

3. Supply pipes clogged.
4. Dirt or water in the fuel.
5. Pump or carbureter out of order.
6. Water in carbureter.
7. Water in the cylinder due to leaky jacket.
8. Inlet valve poorly set or not operating due to broken valve stem, weak or broken spring, valve sticking or broken.
9. Poor compression due to leaky or broken piston rings, improper seating of valves, or to other leaks from the cylinder to the outside.
10. If the exhaust pipe or muffler are clogged the engine will fail to start.

In any of the above cases the remedies are self-evident.

Causes of Motor Failing to Run.—A motor will sometimes start, but will soon afterward slow down and stop. This may be due to:

1. Fuel tank being empty or fuel pipe becoming clogged.
2. Poor or insufficient lubrication, which may cause the seizing of the piston or of the bearings.
3. Wire being jarred loose from its terminal, timer slipping on shaft or to some other fault in the ignition system, such as weak cells, or vibrator or induction coil becoming stuck.
4. Engine carrying too great a load.

Running a Gas Engine.—It is best to keep one man responsible for the care of an engine. The engine should be kept clean and all the parts should be examined frequently to see that everything is in the best working order.

If an engine runs well at no load but will not carry its rated load, this may be due to: poor compression, poor fuel, defective ignition, poor timing of ignition, incorrect valve setting, incorrect mixture, leaky inlet or exhaust valves, too much friction at bearings, or to engine being too small for the rated load.

The operator can usually tell as to whether the correct mixture is being admitted into the cylinder by watching the exhaust. Black smoke issuing from the exhaust pipe means that the mixture is too rich in fuel. This should be remedied by decreasing the amount of fuel supplied or by increasing the air supply. Insufficient fuel in the mixture, as explained in the section on Carbureters, will cause the engine to miss explosions and may even cause backfiring.

Premature ignition, often called preignition, is due to the deposition of carbon and soot on the walls of the cylinder, the compression being too high for the fuel used, by overheating of the piston, exhaust valve or of some poorly jacketed part.

Deposition of carbon on the cylinder walls is usually caused by the use of either an excessive amount or of a poor quality of lubricating oil. This will not only cause preignition, but may also impair the action of the valves, igniter and piston rings. Carbon deposits will also be produced if the mixture is too rich.

Insufficient lubrication may result in abrading surfaces of piston and cylinder.

It is well not to economize when buying gas engine cylinder oil. Due to the high temperatures developed inside of the engine cylinder and to the absence of moisture, a cylinder oil should be selected which is light and thin, which will withstand high temperatures and will leave no carbon deposits. A cylinder lubricating oil well suited for steam engine use will not do at all for gas engine cylinder lubrication.

For the bearings and other rubbing parts outside of the cylinder, a good grade of machine oil will be found satisfactory.

A blue smoke at the exhaust indicates that too much cylinder oil is being used.

Pounding in gas and oil engines is either due to preignition, the causes of which were outlined above, to lost motion in some bearing of the engine, or to the engine being loose on its foundation.

In the case of oil engines using a water spray with the fuel, too little water will result in preignition and consequent pounding. This should be remedied by supplying more water with the fuel. Too much water will be indicated by white smoke issuing from exhaust pipe.

In the case of a gasoline engine, white smoke at the end of the exhaust pipe usually indicates water in the gasoline, which may be due to a leaky jacket or to some other cause.

In regard to the temperatures of the jacket water, this depends on the compression carried and on the size of the engine. With small engines of the hopper-cooled type the jacket temperature is near the boiling point of water. Ordinarily a temperature of about 150° F. will give good results.

CHAPTER VII

TRACTION ENGINES AND AUTOMOBILES

Traction Engines

Fundamental Parts of a Traction Engine.—A steam or a gas engine, explained in the previous chapters, can be converted into a traction engine by mounting it on trucks and providing additional mechanisms, so that the engine will not only be capable of producing rotation at a shaft, but will also move itself over fields and highways, thus performing the work of many horses in a cheaper, quicker and better manner.

All traction engines must consist of the following fundamental parts:

1. **Some Form of Motor.**—This in the case of steam traction engines consists of an engine and boiler. Gas traction engines employ an internal combustion engine burning gasoline, kerosene or solar oil.

2. **Engine Accessories.**—Steam traction engine accessories include valves and piping from boiler to engine, fuel hopper, water tank, safety valve, water glass, steam gage, blow off, pump or injector or both, a stack and spark arrester. Some steam traction engines have also a feed water heater which heats with exhaust steam the feed water before it enters the boiler. The accessories of the gas traction engine are fuel tanks, water tanks, batteries and battery boxes, magnetos, carbureters.

3. **Reversing Mechanism.**—Reversing of a steam traction engine is accomplished either by a link similar to that used in locomotive practice, or by some form of single eccentric radial valve gear. It is more difficult to reverse a gas traction engine and a train of gears must be employed.

4. **Steering Mechanism.**

5. **Transmission Mechanism.**—The speed of the engine is too great for direct utilization, and a train of gears must be interposed between the engine and drive wheels.

6. **Differential or Compensating Gear.**—The purpose of this is to allow one drive wheel to revolve independently of the other, this being necessary when turning corners, as will be explained later.

7. **Friction clutch** for disengaging engine from propelling gear, so that the power of the engine can be utilized for the driving of separators or other machinery. Some makes have no friction clutch.

8. **Trucks** for mounting engine and other parts.

9. **Traction or drive wheels** (Figs. 145 and 146), which must be provided with lugs to give them a firm footing on the ground, and with mud shoes.

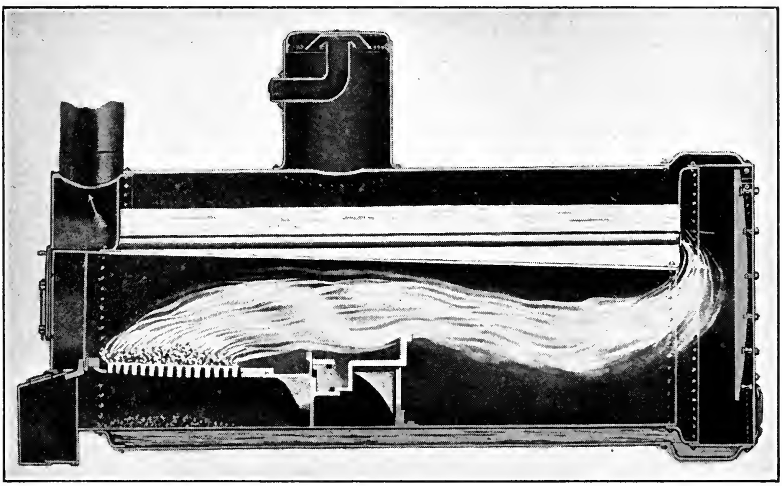


Fig. 142.

10. **Front Wheels.**—These are made smaller and lighter than the traction wheels, and are provided with a smooth tire. To prevent skidding the front wheels are built with a flange in the center (Figs. 145 and 146). The front wheels turn upon an axle which is attached to a ball and socket joint, or to some similar mechanism, so as to allow for uneven ground and also to facilitate steering.

Steam Traction Engines.—The boiler of the steam traction engine is internally fired. Some builders utilize the return flue type (Fig. 142), others a locomotive type (Fig. 143).

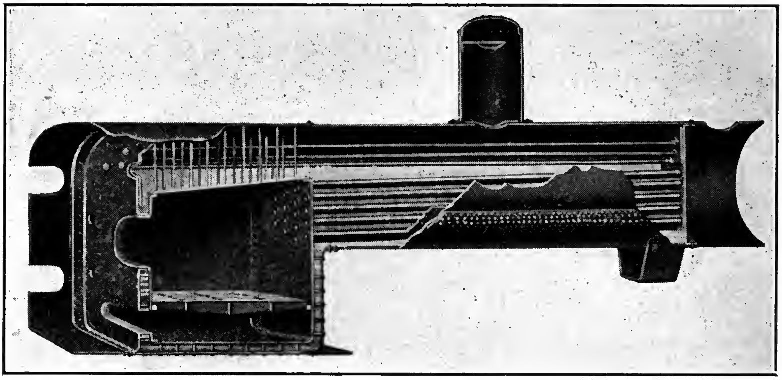


Fig. 143.

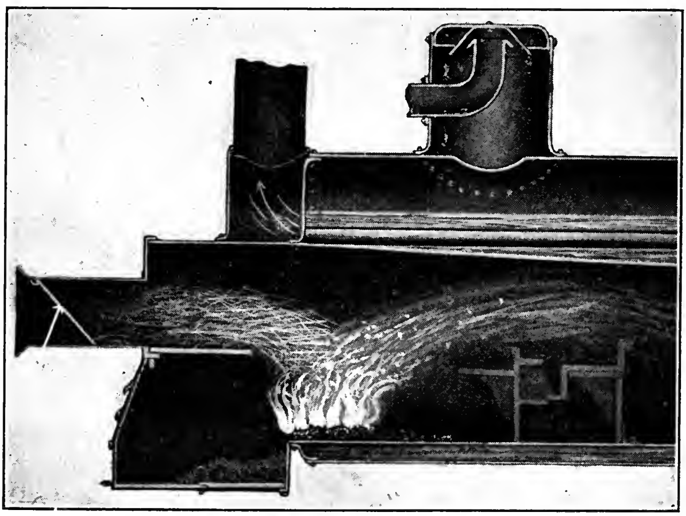


Fig. 144.

When using straw for fuel, the furnace is modified as shown in Fig. 144. Slab grates are then substituted for the ordinary coal grates and the straw is fed through a chute S. A hinged trap

T is provided to prevent the entrance of air when the straw is not being fed.

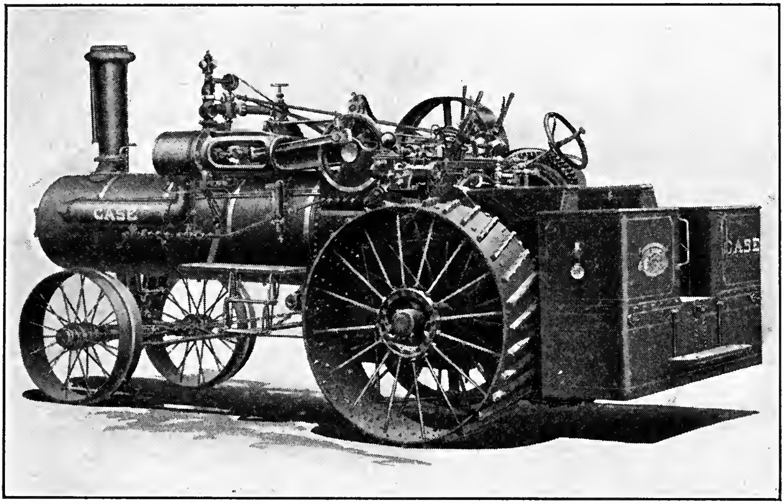


FIG. 145.

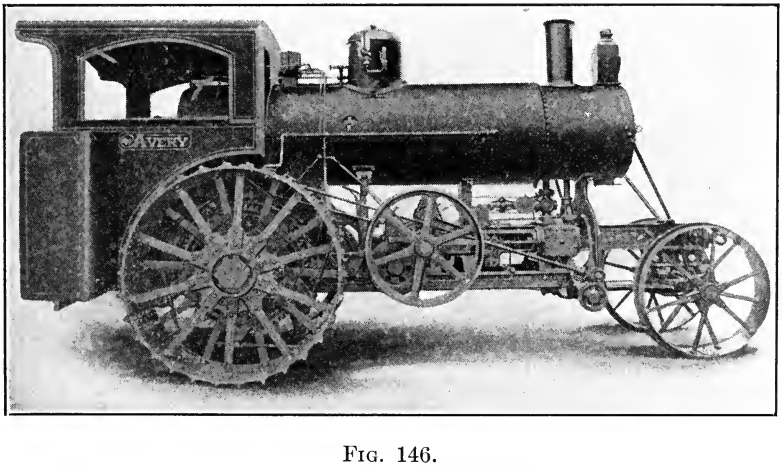


FIG. 146.

In some makes of traction engines, the boiler is mounted upon the truck and is used as the foundation for the engine (Fig. 145).

Other types (Fig. 146) have the engine mounted under the boiler, the frame supporting both engine and boiler.

Two types of feed pumps are used on steam traction engines:

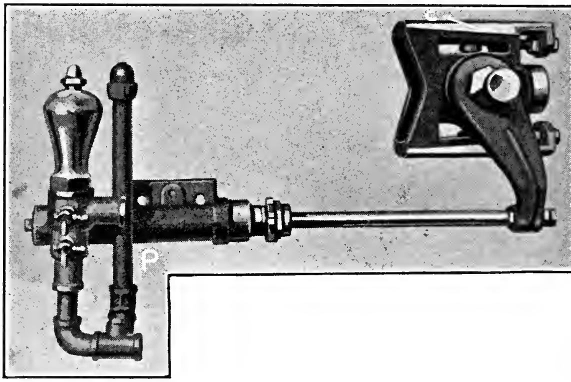


Fig. 147.

The independent pump which is similar to the types illustrated in Chapter IV. Some traction engines use a cross-head pump P (Fig. 147), which is driven from the engine cross-head C. As

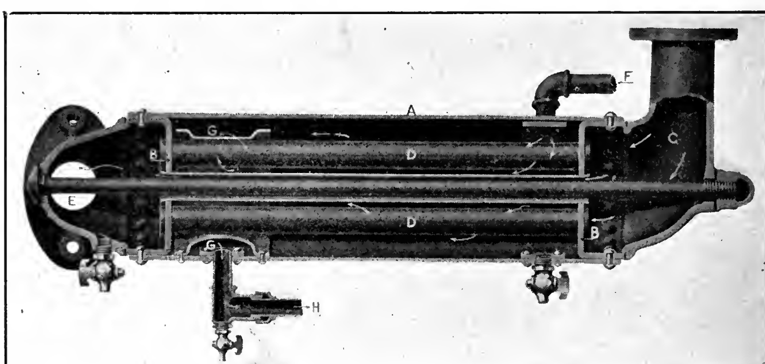


Fig. 148.

in the case of stationary engines, two independent methods should be employed for feeding water into a traction engine boiler, using either two pumps or an injector and a pump.

Feed water heaters are used on some traction engines. The type often employed is illustrated in Fig. 148. The feed water passes through the annular space between the tubes and the exhaust steam surrounds the tubes.

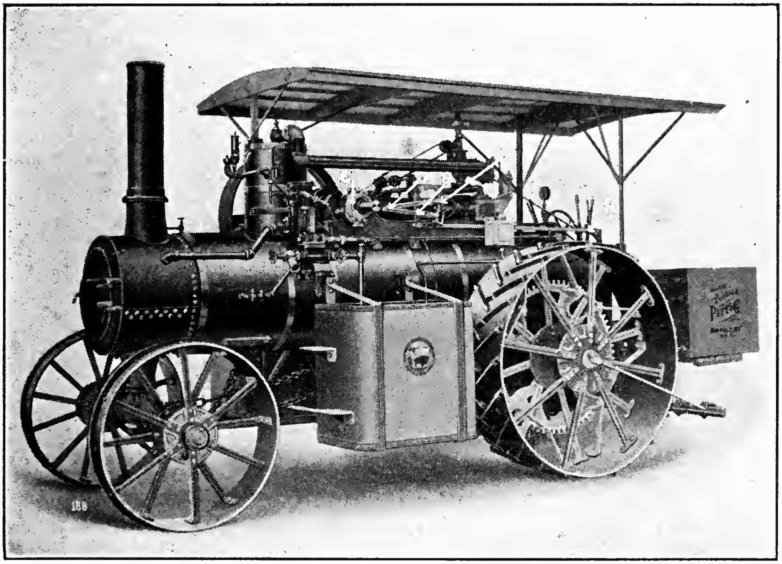


Fig. 149.

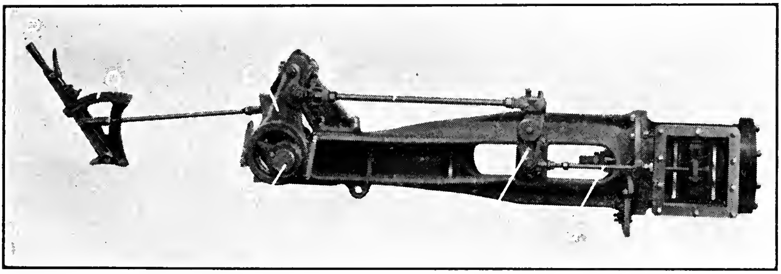


Fig. 150.

Traction engines using wood or straw are usually provided with some form of spark arrester. This consists of a screen dome placed over the stack, or of some arrangement for deflecting the smoke, so that the sparks will be deposited in water.

The type of engine employed is some simple form of steam engine with a slide valve. Some traction engines have double-cylinder engines. Compound engines are also used to some extent.

The details of the engines, governors and accessories do not differ from those described in chapter V.

A steam traction engine can be reversed either by a Stephenson link similar to that used on locomotives, or by some form of single eccentric radial valve gear.

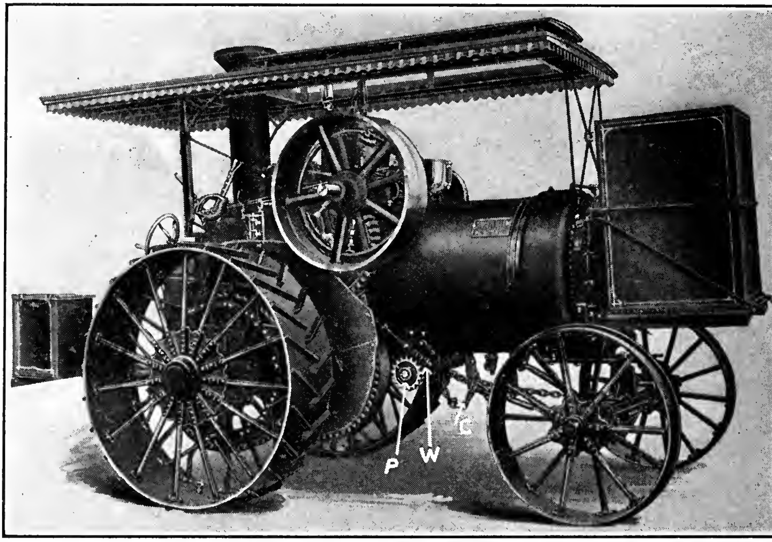


Fig. 151.

To reverse an engine by means of the Stephenson link, it must be provided with two eccentrics, placed opposite to each other on the crank shaft, each being connected by an eccentric rod to the end of a link. A block connected to the valve slides along a groove in the link.

This type of reversing link as applied to a traction engine is illustrated in Fig. 149. The two eccentrics shown at E are attached to the curved link L by means of the eccentric rods A and B. The position of the link is varied by the reverse lever through the reach rod R. In one position of the link the motion to the valve is given by one eccentric, driving the shaft in one direction. This direction of rotation is reversed by raising the link, so that the valve receives motion from the other eccentric. If the reverse lever is moved so that the block is in the middle of the link, the motion given by both eccentrics will be equal and opposite, and the valve will have no motion.

Most traction engines employ a single eccentric radial valve gear (Fig. 150). This reversing gear consists of an eccentric B fastened on the crank shaft. The eccentric strap has an extended

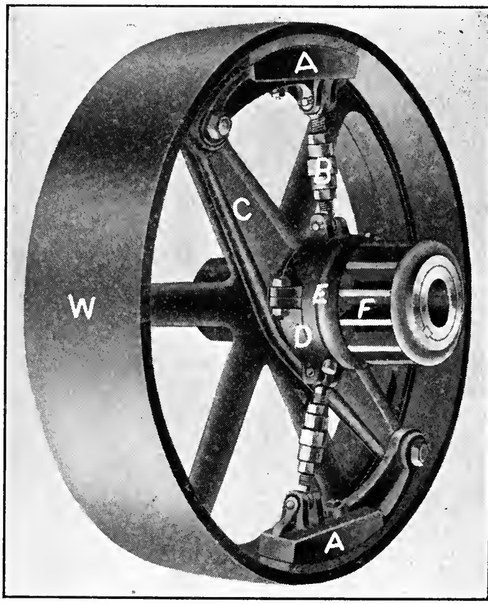


Fig. 152.

arm C, pivoted in a block E, which slides up and down in a guide F, and gives motion to the rod D, which is transmitted to the valve through the rocker K and valve stem J. The guide F is hung on a trunnion and it can be tilted in any direction by the reverse lever R. The angle at which the guide F is set determines the direction in which the engine is to run. The quadrant Q is usually provided with three notches. When the reverse lever is in the central notch no motion is given by the block E to the valve rod J. In the position shown, the block E sliding up and down in the guide F moves the valve in one direction. Placing the reverse lever in the notch at the extreme right reverses the engine.

Steering is accomplished by turning the front axle. This is done by chains C (Fig. 151) which wind upon a spool. The spool is operated by hand through a worm W and pinion P (Fig. 151). Another method is to operate a screw by the worm

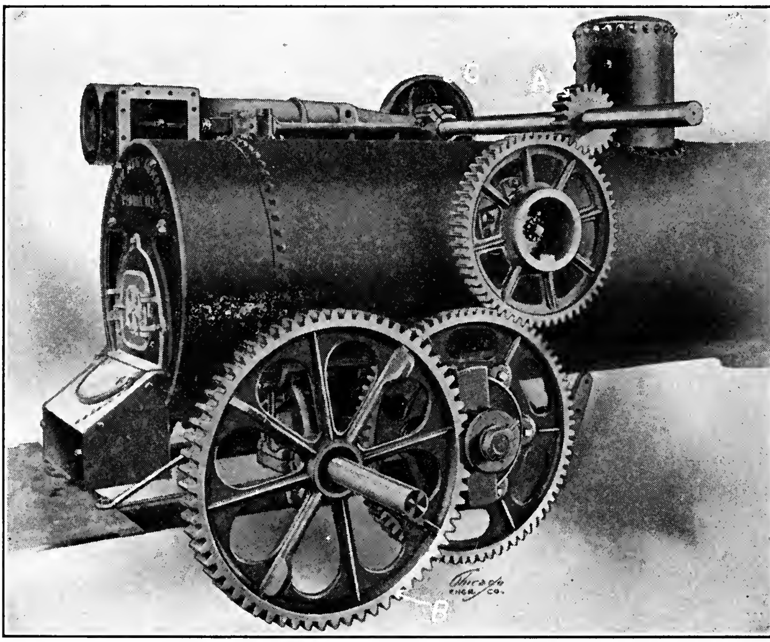


Fig. 153.

and pinion, the screw moving a nut which is connected by a system of levers to the front axle. In large traction engines steering is accomplished by power furnished by the engine through a friction disc.

A friction clutch, the function of which is to disengage the engine from the propelling gear, is illustrated in Fig. 152. The flywheel W is fixed to the engine shaft, and, when used as a belt wheel, it is not connected to the arm C, and thus does

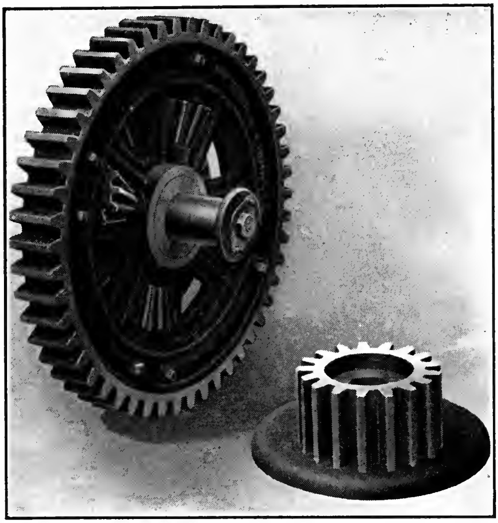


FIG. 154.

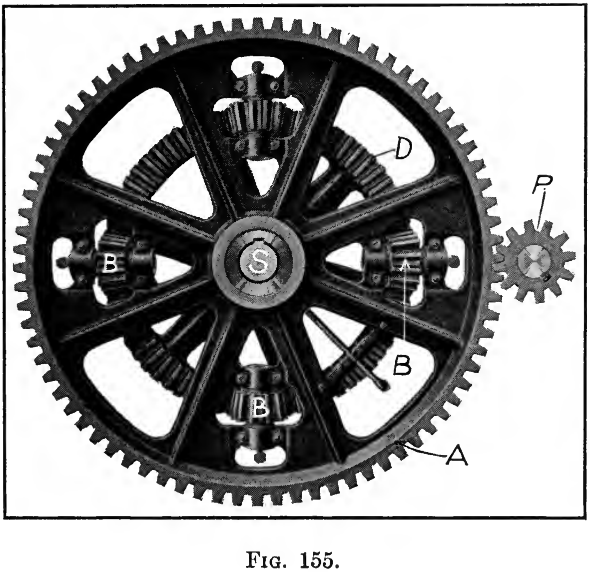


FIG. 155.

not transmit motion to the pinion F which is rigidly connected with the arms C. When the clutch is thrown in, pressure is applied at E which rests in a groove in the piece D. This results in B crowding the shoe A against the inner rim of the flywheel. The friction clutch has two shoes made of wood or of some other yielding material AA, which press against the inner rim of the flywheel when the clutch is thrown in, and this transmits the motion of the engine through the arms C and pinion F to the transmission.

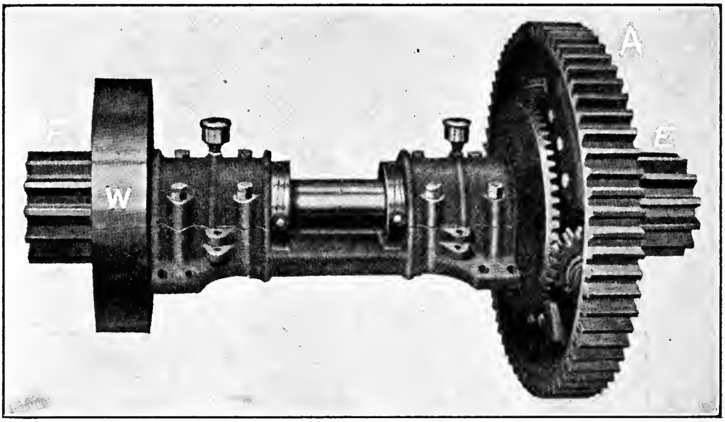


Fig. 156.

The transmission mechanism (Fig. 153) delivers the power from the engine to the traction wheels which must revolve slower than the engine crank shaft. The gear A receives motion from the engine and delivers this through the train of gears to the gear B, which is connected to the traction wheel.

Differentials for Traction Engines.—When a traction engine turns a corner, the drive wheel on the outside of the curve must turn faster than that on the inside. If the two drive wheels were rigidly connected, one would have to skid or slip, when turning a corner, and this would throw a great strain on the wheels and axles. The differential, sometimes called a compensating gear, allows one drive wheel to move ahead of the other.

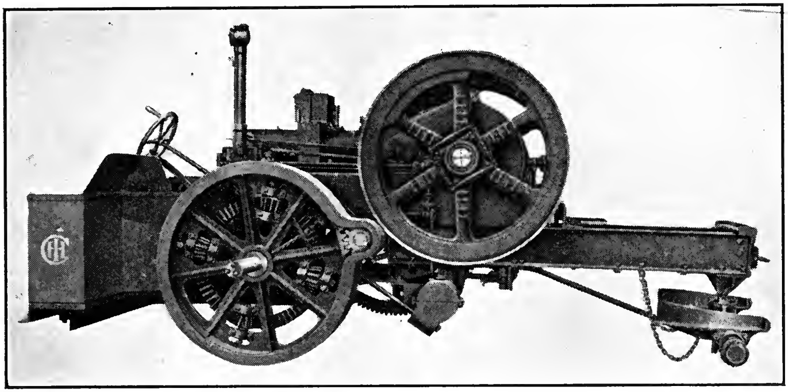


FIG. 157.

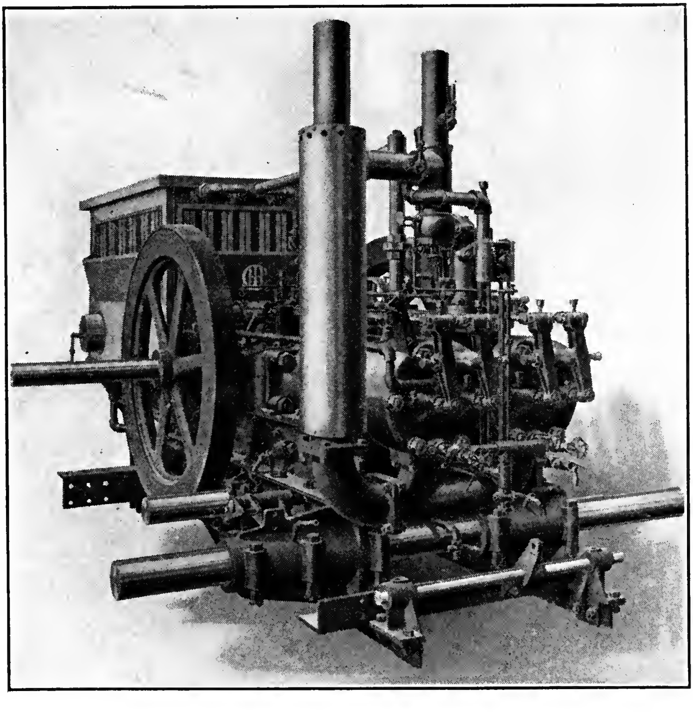


FIG. 158.

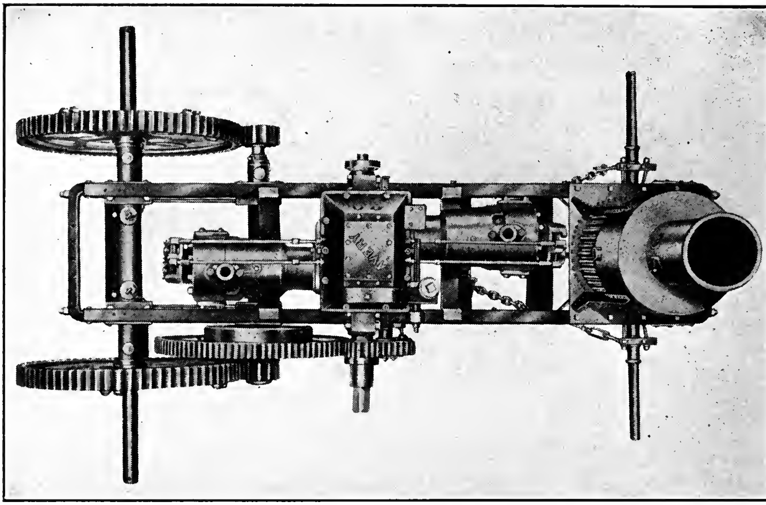


Fig. 159.

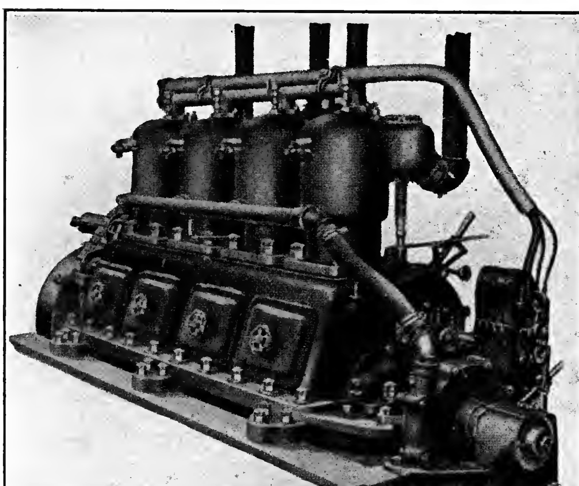


Fig. 160.

The differential can be placed between the two drive wheels on the rear axle. A more common method is to have the differential on a separate shaft, the traction wheels being driven from that shaft by means of pinions.

The principle of differentials as applied to steam and gas traction engines is illustrated in Figs. 154 and 155. The differ-

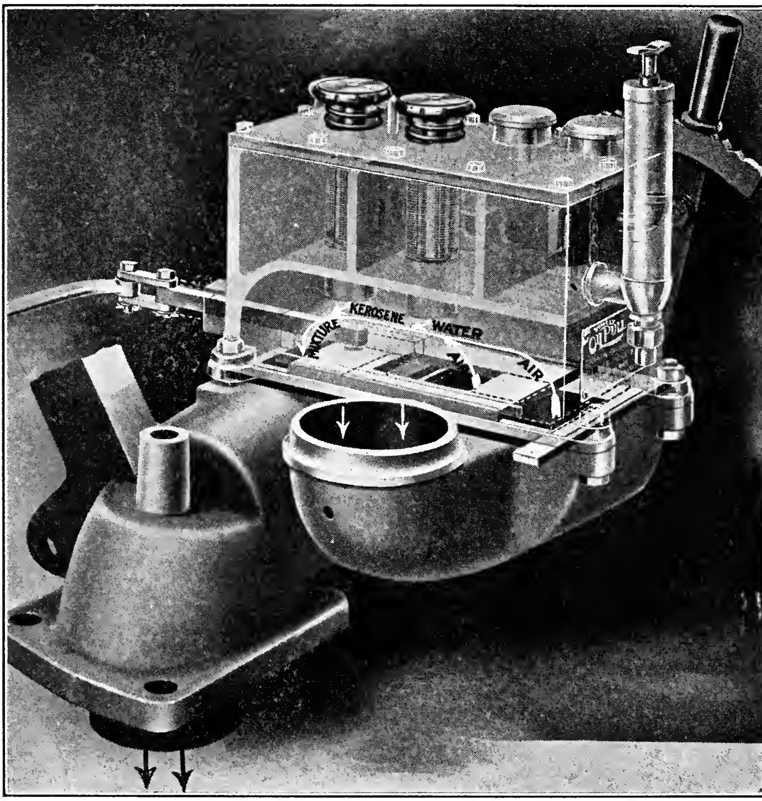


Fig. 161.

ential shaft S consists of two shafts, each being connected either directly or through gears to the drive wheels. Two bevel gears C and D are keyed to those two differential shafts and engage several bevel pinions, marked B, which turn freely on their respective shafts. The power from the engine is trans-

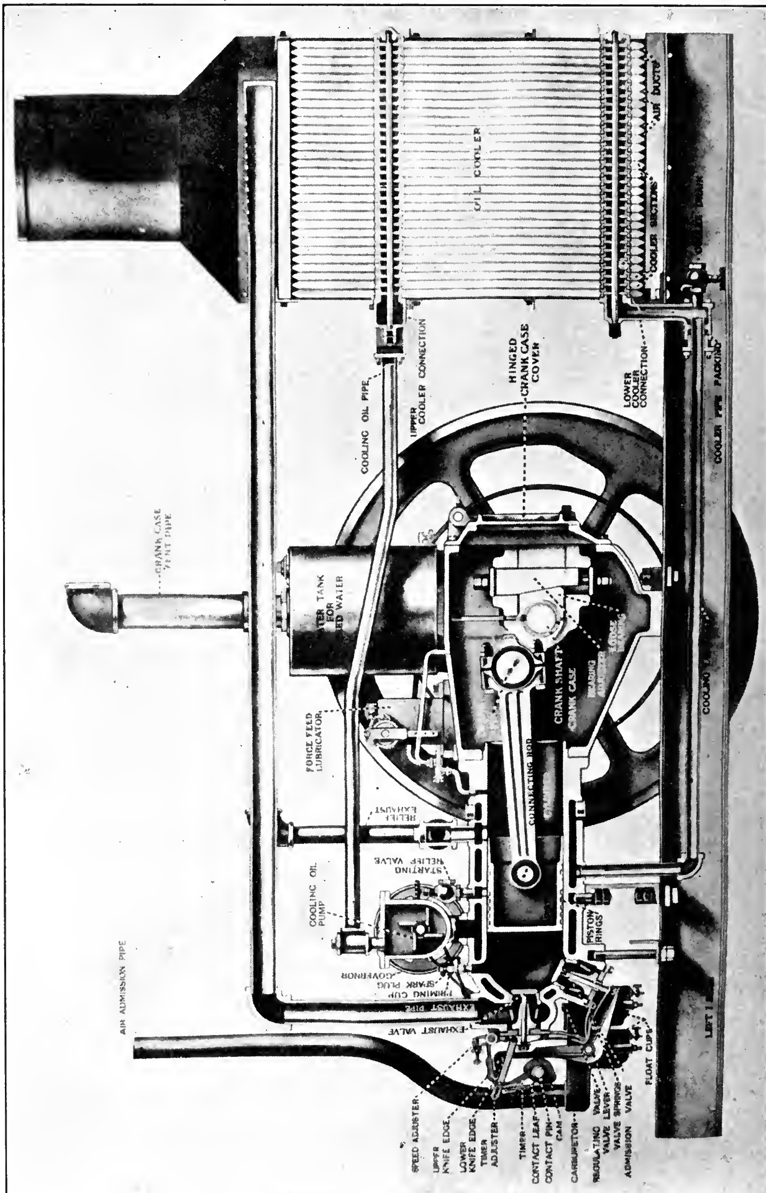

AIR ADMISSION PIPE
CRANK CASE VENT PIPE
COOLING OIL PIPE
UPPER COOLER CONNECTION
HINGED CRANK CASE COVER
LOWER COOLER CONNECTION
COOLER PIPE PACKING
OIL COOLER
AIR DUCTS
COOLER SECTIONS
FORCE FEED LUBRICATOR
RELIEF EXHAUST
STARTING RELIEF VALVE
COOLING OIL PUMP
GOVERNOR
SPARK PLUG
PRIMING CUP
EXHAUST PIPE
EXHAUST VALVE
CONNECTING ROD
CRANK SHAFT
CRANK CASE
PISTON RINGS
SPEED ADJUSTER
UPPER KNIFE EDGE
LOWER KNIFE EDGE
TIMER ADJUSTER
TIMER
CONTACT LEAF
CONTACT PIN
CAM
CARBURETOR
REGULATING VALVE
VALVE LEVER
VALVE SPRINGS
ADMISSION VALVE
FLOAT CUPS

FIG. 162.

mitted through the pinion P to the large spur gear A. When the engine is going ahead on a level road and both drive wheels are rotating at the same speed, the two bevel gears C and D will also revolve at the same speed and the small pinions marked B will remain stationary. In turning a corner or in meeting some obstruction, if the drive wheel connected to C moves slower than that connected to D, the pinions B will revolve on the bevel gear D at a faster rate. In other words,

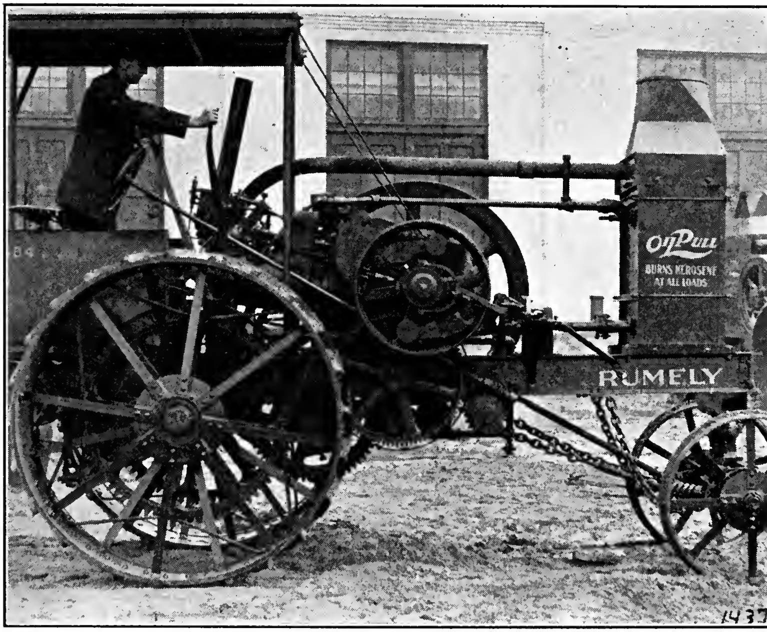


FIG. 163.

the difference in motion between the two drive wheels is compensated for by the revolution of the pinions B.

Another gas traction engine differential is shown in Fig. 156, the letters designating the same parts as in Figs. 154 and 155. The two pinions E and F connect the differential with the two drive wheels. Bevel gear C is at the right of spur gear A. W is a brake wheel.

Gas Traction Engines.—The term gas traction engines is applied to such as are propelled by internal combustion engines. The fuels most commonly used are gasoline, kerosene and solar oil.

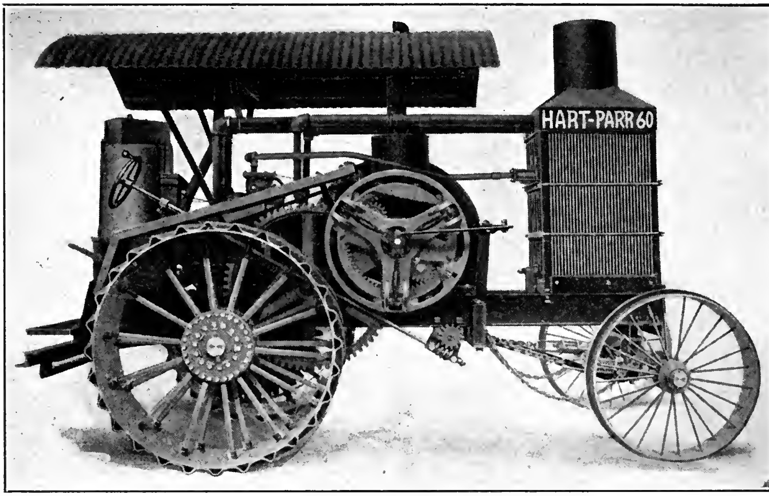


Fig. 164

All gas traction engines use internal combustion motors working on the four-stroke Otto gas engine cycle. The types of engines

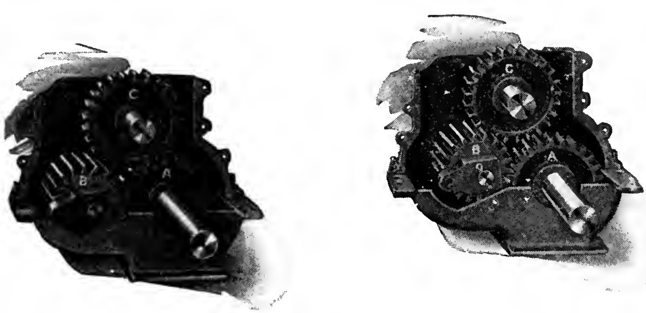


Fig. 165.—Reverse gears.

used are single cylinder (Fig. 157), twin cylinder (Fig. 158), two cylinder opposed (Fig. 159) and four cylinder motors (Fig. 160).

The details of construction of the engines and auxiliaries are very similar to those of stationary gas and oil engines explained in Chapter VI.

Some gas traction engines employ the make and break system of ignition very successfully. The majority, however, use the jump spark system. Magnetos furnish current for ignition. Some makes start on the magneto, but the majority use dry or storage batteries for starting.

Both the hit and miss and the throttling systems of governing are used, the hit and miss system being more common in the smaller sizes and the throttling governor in larger gas traction engines.

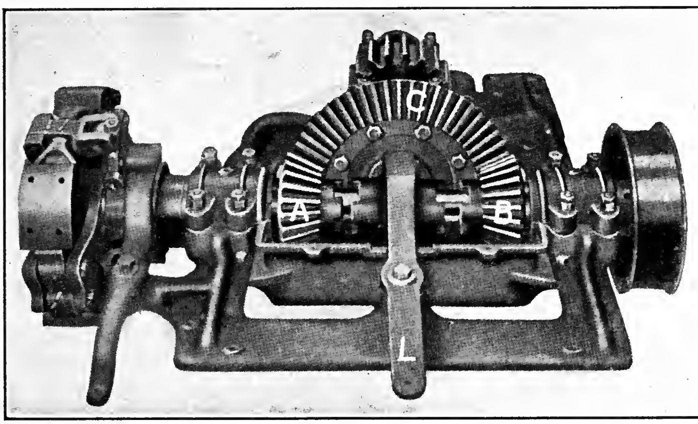


Fig. 166.

Most traction engines are provided with two fuel tanks, and are built to operate either on gasoline or on kerosene. When using kerosene, water is injected with the fuel to prevent preignition.

Float feed carbureters are most commonly employed, but mixer valves with fuel pumps will also be found, similar to those used in connection with stationary gasoline engines. Fig. 161 shows one form of carbureter. The three compartments from right to left are for gasoline, water and kerosene. The lower section is a mixing chamber. A plate controlled by the governor varies the quantity of the mixture admitted.

Some engines are provided with an auxiliary relief exhaust port (Fig. 162). The advantages claimed for this are that the exhaust valves do not have to open against as great a pressure

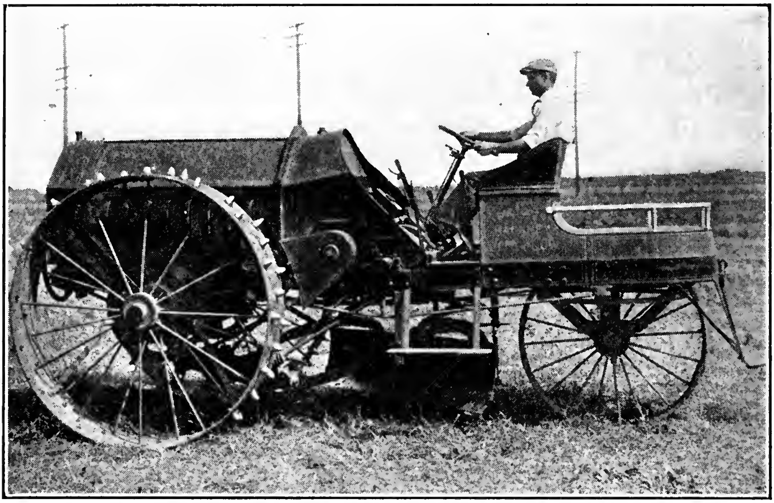


Fig. 167.

Fig. 168.

and that the hottest gases escape through the relief port and thus the life of the exhaust valve is prolonged.

Fig. 169.

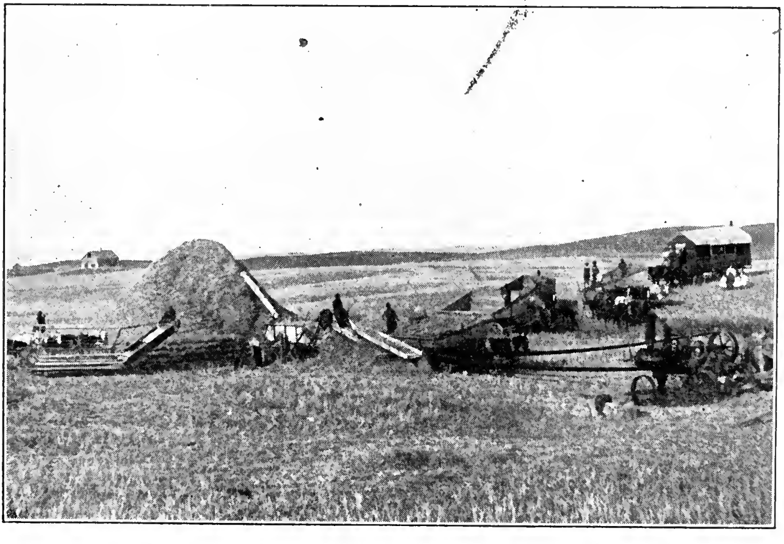


Fig. 170.

Gas traction engines are either water cooled or oil cooled, and are provided with a radiator (Fig. 162) for the purpose of cooling

Fig. 171.

Fig. 172.

the water or oil after it has absorbed heat from the cylinder walls.

Fig. 173.

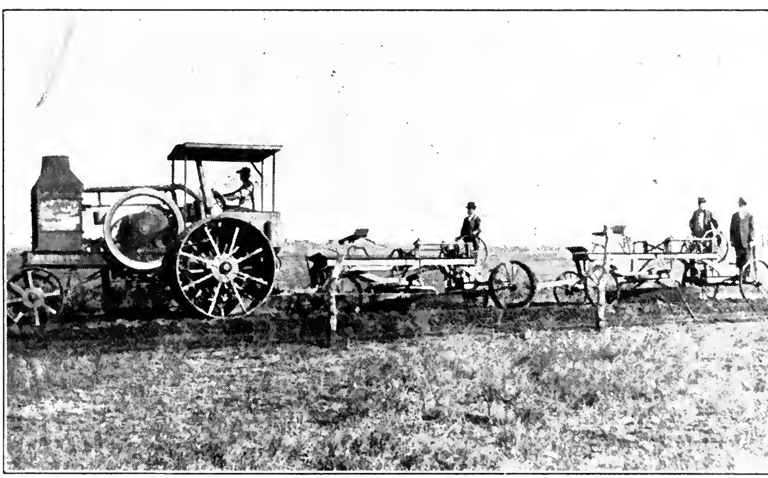


Fig. 174.

As in steam traction engines, steering is accomplished by moving the front wheels (Figs. 163 and 164). The general details of the transmission train (Fig. 163) are also similar to those of steam traction engines.

The engine illustrated in Fig. 164 is provided with two clutches, one for forward and one for return. Both clutches are operated by a single lever.

Another method of reversing a gas traction engine is shown in Fig. 165. Gear A is located on the clutch shaft. When the engine is traveling forward gear A acts directly on pinion C. To

Fig. 175.

reverse the engine a lever slides the gear A out of mesh with the pinion B and engages it with pinion C which meshes with B. Both positions are illustrated in the figure.

Still another method of reversing is given in Fig. 166. The two bevel pinions A and B are free on the transmission shaft. By moving the lever L to the right bevel pinion B engages bevel gear C and the drive is in one direction. To reverse, pinion A is shifted by the lever A to mesh with C, pinion C gearing with B.

The other details of gas traction engines, such as the clutch for changing from traction to belt power, construction of front and traction wheels, are very similar to those of steam traction engines.

Uses of Traction Engines.—A traction engine can be used for plowing, seeding, packing, harrowing, harvesting, threshing, hay baling, road building, ditch digging and marketing. Besides these field operations it can do most of the work of a stationary engine. Among the uses of a traction engine on belt may also be mentioned the grinding of feed, corn shelling, husking and shredding, ensilage cutting, silo filling, wood sawing, well drilling, rock crushing, driving cement mixers and electrical dynamos, pumping water, and other uses.

The small traction engine illustrated in Fig. 167 is designed for moderately small farms and is applicable for road grading and plowing. It may also be used for pulling harrows, seeders, etc.

With a traction engine the processes of plowing, seeding and harrowing can be carried on in one operation (Fig. 168). Plowing with a tractor (Fig. 169) is done deeper and more uniformly than is the case with animal power. Harvesting with steam and gas traction engines is illustrated in Figs. 170 and 171. The application of the traction engine to hay bailing, silo filling and road building is illustrated in Figs. 172, 173 and 174. A traction engine moving a barn is shown in Fig. 175.

Rating of Traction Engines.—Two ratings are usually given to traction engines. The first is in brake or belt horse-power. This means the actual power developed at the shaft of the engine, which can be utilized for driving various machines by means of belt drive.

The other rating is in traction or drawbar horse-power. To obtain the traction horse-power the amount of power lost in transmission to the drive wheels and that required to propel the traction engine must be subtracted from the brake horse-power developed at the shaft of the engine.

The traction horse-power depends on the kind of transmission gearing and on the character of the roads over which the traction engine must be propelled. It is equal from one-half to two-thirds of the brake horse-power. As an illustration, a traction engine equipped with a 40 h.p. engine will be able to produce only 20 to 27 h.p. at the draw-bar under ordinary conditions.

Management of Traction Engines.—The general directions given regarding the care of stationary steam and gas engines apply also to the motors of steam and gas traction engines. Bearing surfaces must be kept well lubricated or they will wear out, and lost motion in bearings should be avoided to prevent pounding and broken crank shafts.

Before taking out a traction engine on the road, it should be gone over carefully, all nuts tightened, bearings properly set, lubricators filled, and clutch adjusted so that both shoes come in contact with the inside of the wheel at the same time. Boilers, engines and auxiliaries should be working properly. If possible enough fuel, water and oil should be taken for the days run, so as to avoid delays.

At the end of the day's run the engine and all parts should be again carefully examined to see that every bearing gets its proper lubrication and runs cool. Every oiler and grease cup should be examined and filled. Parts such as connecting rods should be tested for end play. The valves should be examined for wear. In the case of gas traction engines it may be necessary to grind the exhaust valves about every two weeks during the heavy season, so as to prevent the loss of compression due to valve leakage. This is done with oil and flour emery dust. The inlet valves will require but little attention. In cold weather all parts should be drained to prevent freezing.

In operating a steam traction engine on the road the boiler should be kept with water to the proper level. This is best done with the pump forcing the water through the feed-water heater. The injector should be kept in reserve for emergencies. The fire should be kept thin. Care must be taken not to allow the engine to remain with its back end elevated for any great length of time, as this may result in the over-heating of the crown sheet. The water glass should be blown out two or three times each day and the safety valve should be kept in good working order.

In filling the fuel tanks of gas traction engines, the fuel should be strained through a fine brass screen so as to prevent dirt from getting into the carbureter and supply pipes from clogging.

Traction engine cylinders and valves should be cleaned frequently with kerosene so as to remove carbon and other deposits.

In running a traction engine on the road, the operator should keep his eyes on the front wheels to prevent accidents. In case a traction engine is landed in a hole, it can be pulled out by placing chains, boards or straw under the drive wheels. The same applies when the engine slips. Before crossing a bridge the operator should ascertain that it is safe. In the case of doubt, planks should be placed to distribute the load.

A good operator handles a traction engine slowly and deliberately, and never hesitates to stop, should something go wrong with any part of the engine.

In laying off the engine for the winter, it should be placed under cover and be protected from rain and snow. It is well to remove pistons from the cylinders of gas traction engines, clean all deposits and then oil pistons, cylinders and valves with a heavy oil. Magnetos and batteries should always be removed to a dry place. All parts should be carefully drained. In fact it is well to remove all drain cocks so as to prevent any water from remaining in cylinders and tanks.

Automobiles

Types of Automobiles.—An automobile can be propelled by a steam engine, by an internal combustion engine, or by an electric motor with current secured from storage batteries.

The majority of modern automobiles are propelled by internal combustion engines using gasoline as fuel.

Steam and electric cars operate more quietly and can be more easily controlled than gasoline cars. Then the electric car has the additional advantages of cleanliness and ease of starting, while the steam car has a greater range of power.

To offset the above advantages, electric cars are more expensive to operate, can be used only where there are facilities for charging storage batteries, and will operate only on runs of about one hundred miles, before they have to be recharged

Steam cars require considerable time to start after a long stop, and also greater skill in operating than gasoline or electric cars.

The gasoline automobiles possess also the additional advantages, in that they are manufactured in many different types, and can be secured at a great variety of prices, from several hundred up to many thousand dollars per car.

Most of the modern makes of gasoline cars are supplied with automatic starters, so that the cars may be started from the seat. This is acccomplished by a spring, an air motor, or by an electric motor.

Gasoline Automobiles.—The general details of an automobile power plant are illustrated in Fig. 176. Most automobiles have

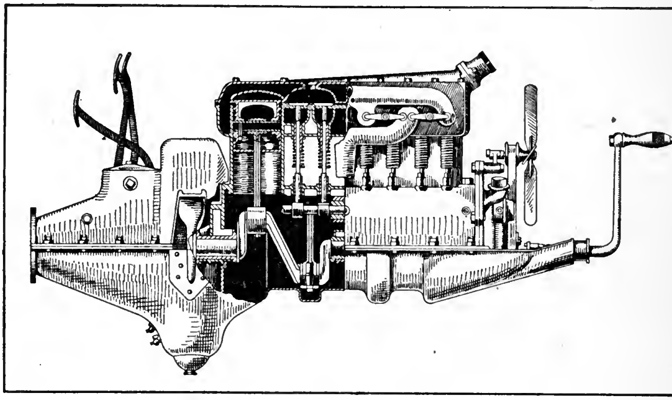


Fig. 176.

four- or six-cylinder vertical gasoline engines working on the four-stroke Otto gas-engine cycle. There are several makes of automobiles using the two-stroke cycle engine. Then small automobiles are sometimes equipped with a two-cylinder or even single-cylinder horizontal engine. The more cylinders are employed, the easier it is to start and to run an automobile slowly without stopping.

Automobile engines are most commonly water cooled and are provided with radiators, the purpose of which was explained in connection with gas traction engines.

Jump spark ignition is always employed in automobiles and most modern cars are provided with high-tension magnetos.

The carbureters are of the float-feed type as explained in Chapter VI.

The valve shaft is usually driven by gears if parallel to the crank, and by a worm and wheel if at right angles to the shaft.

The poppet type of valve is used on most automobiles, but a slide valve has recently been perfected which is giving excellent results.

The power from the motor crankshaft is delivered to the fly-wheel which forms the outer part of the clutch. The inner part of the clutch is connected to the transmission and speed-changing mechanism, through the differential and to the drive wheels. A clutch is necessary in a gasoline automobile, as the gasoline engine cannot be started under load.

A transmission and speed-changing train must be provided between the clutch and drive wheels in a manner similar to that explained in connection with gas traction engines. The transmission mechanism consists either of a train of gears or of friction discs.

The sliding-gear system of transmission is most commonly employed. This consists of an auxiliary shaft which is connected to the drive of the car and gears with the engine shaft. The change of speeds and reversal of motion is accomplished by sliding the drive gears on a square shaft.

In the case of the friction drive a flat-faced metal disc is attached to the motor crank shaft. The other part is a wheel with a fiber rim keyed to a shaft, but free to move back and forth on the shaft. This shaft is mounted parallel to the face of the disc wheel. When the wheel with the fiber rim is near the center of the disc, the car is on slow speed. The farther out from the center this wheel is shifted the faster is the speed. If this wheel is shifted across the center, the car travels backward. A friction drive applied to an automobile is illustrated in Fig. 266, Chapter XI.

The automobile differential works on the same principle and serves the same purpose as the differential of traction engines. It differs from the traction engine differential, in that it is entirely enclosed, and that the train of gears for speed charging is at another place.

Automobile Troubles and Their Remedies.—In Table 6 will be found some of the more common causes of automobile troubles. This list was given by C. G. Anderson as a part of an address delivered by him before the Gas Engine class at the Kansas State Agricultural College.

TABLE 6—AUTOMOBILE TROUBLES AND THEIR REMEDIES.

- Case 1 Motor will not run.
  - Ignition in working order.
    - Compression.
      - Carbureter in working order.
        - Ignition out of time (rare—due to incorrect mounting).
        - Inlet manifold broken or perforated.
        - Exhaust valve remains seated (broken spring or stem).
        - Links to throttle work poorly or not at all.
        - Water in gas.
        - Gasoline cock is closed or feed pipe clogged or broken.
        - Gas tank empty.
      - Carbureter not in working order.
        - Carbureter flooded (needle valve needs grinding—float punctured or too heavy).
        - Too little gas in float chamber (needle valve badly set—float too light when replaced—feed pipe obstructed or jet obstructed).
        - Balance levers broken or worn.
    - No Compression.
      - Break or trouble outside of motor.
        - Valve broken.
        - Valve stem dirty or sticks in guide.
        - Valve spring broken or has temper drawn.
        - Cylinder or explosion chamber cracked.
      - Break or trouble inside of motor.
        - Broken piston rings.
        - Piston ring slots in line or rings set wrong.
        - Piston rings gummed to cylinder walls.
        - Broken crank shaft, connecting rod, loose cam, etc.
        - Water leaks into cylinder.
  - Ignition not in working order.
    - With storage or dry battery unscrew spark plug.
      - No spark at outside end of spark plug.
        - Spark at Trembler.
          - Sufficient voltage or amperage.
            - Stuck or wrongly set trembler.
            - Trembler screws loose on coil.
            - Leak between coil and spark plug.
            - Broken secondary wire.
          - Insufficient voltage or amperage.
            - Change or renew batteries.
        - No spark at Trembler.
          - Run down batteries.
          - Leak in primary circuit.
          - Dirty trembler, or platinum points too far apart.
          - Timer misplaced.
      - Spark at outside end of plug (unscrew it).
        - Broken spark plug.
        - Dirty spark plug.
        - Spark plug points too far apart.
        - Voltage too low for passage of spark, with plug in cylinder.
    - With Magneto.
      - Spark at outside end of spark plug.
        - Magneto out of time.
        - Wiring improperly connected up.
      - No spark at outside end of spark plug.
        - No contact—broken wire.
        - Timer badly set or damaged.
        - Carbon brushes worn or gone.
        - Distributor contacts fouled (worn down—not making contact).
        - Wire attached to wrong terminal—particularly wire from coil.
        - Poor insulation of wipers and spark plug.

TABLE 6.—AUTOMOBILE TROUBLES AND THEIR REMEDIES.—*Continued.*

CASE 2
Motor Starts and Stops after a few Revolutions or Cannot be made to Run for any Length of Time.

- Motor seized from lack of oil or water.
- Too much oil in crank case.
- Water has entered cylinders through cracks.
- Faults due to poor carbureter adjustment, float is stuck, clogged feed pipe, etc.

CASE 3
Motor runs normally but car does not.

- Clutch works normally.
  - Change speed lever indicates no trouble.
    - Shaft drive.
      - Sheared key on live axle.
      - Differential speeder broken.
      - Broken drive shaft—key sheared on same.
      - Broken bevel gear.
      - Twisted of mis-aligned drive shaft.
      - Broken universal joint.
    - Chain drive.
      - Loose sprocket.
      - Sheared key or jack shaft similar to above.
  - Change speed lever shows an impediment.
    - Broken or mutilated gears.
    - Broken ball bearings.
    - Sticking or mis-alignment of gear shaft or of their operating mechanism.
    - Deformed gear, loose operating mechanism, interior play and faults.
- Clutch sticks at particular speed.
  - Teeth broken in corresponding pinions.
- Clutch sticks at all speeds.
  - Mis-alignment of transmission shafts.
  - Seized bearings and cages.
  - Foreign bodies between gear teeth.
  - Dragging brake—improper adjustment.
- Clutch will not work at all.
  - Broken or weakened spring.
  - Damaged leather.
  - Shaft out of line or bent.
  - Plates or discs buckled.
  - Sheared keys.
  - Seized shaft.
  - Leather plates or discs "frozen" or gummed up.

Gasoline Motor Cycles.—This chapter would be incomplete without some mention of the gasoline motor cycle, which is becoming very popular even in the rural districts. It is light and can be driven over roads impossible to pass by four-wheel machines.

The power plant of the motor cycle is either a single-cylinder, a twin-cylinder or a four-cylinder engine. The power plant of the latest motor cycles varies in capacity from 4 to 10 h.p.

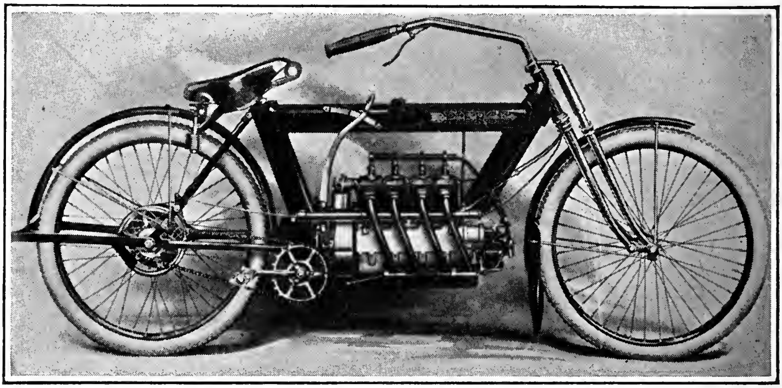


Fig. 177.

The single- and twin-cylinder machines are most popular on account of lower first cost. The motors differ from the automobile motors in that the cylinders are always air cooled. The inlet valve is either mechanically or automatically operated.

Float feed carbureters of the automobile type and high tension magnetos are employed.

Motor cycles are started by the use of the petal, by a hand crank, or by a foot lever. Belt and chain drives are used, the belt drives being more common. Some of the newer models are provided with a clutch to free the engine from propelling mechanism, and operate on two speeds. The general appearance of a four-cylinder motor cycle is illustrated in Figs. 177. All motor cycles operate on the four-stroke cycle, but lately a two-stroke cycle valveless motor appeared on the market.

CHAPTER VIII

WATER MOTORS

A water motor converts the energy possessed by moving or falling water into useful work.

Determining the Power of Streams.—Before explaining the various commercial types of water motors, the method of determining the power available in any water stream will be given.

The power available in any stream depends on the head of water and on the quantity of water which can be utilized in a water motor.

The term head is applied to the fall of water available. The head can be determined most readily by running an engineer's level from a point at the upper line of water flow to a point at the lower line of flow. The vertical distance between the two points gives the head of the stream.

One method of determining the quantity of water available for utilization in a motor, is to find the cross-sectional area of the stream, and to multiply this by the velocity of the stream. The cross-sectional area of a stream can be obtained by multiplying the average depth of the stream by its width. To find the velocity, several floats are dropped in the water at a place where the depth and width is uniform for some distance, noting the number of seconds it takes for the floats to pass a certain distance. Since the velocity of a stream is greatest at the center and is least at the bottom and sides, the velocity as obtained by floats should be multiplied by 0.80 to obtain the average velocity.

As an illustration, the average width of a stream is 10 ft., its average depth is 4 ft. and the velocity of the water, as obtained by floats, is 30 ft. per minute. If the head of the water is 10 ft. calculate the power which could be obtained from a water motor, assuming the various losses in the motor as 30 per cent. and the average stream velocity 0.80 of the float velocity.

The area of the cross-section of the stream $=10\times4=40$ ft.

The quantity of water available per second is equal to

$$40 \times 1/2 \times 0.80 = 16 \text{ cu. ft.}$$

As the weight of a cubic foot of water is 62.4 lb. at ordinary temperatures, the weight of water delivered to the motor per second is,

$$62.4 \times 16 = 998.4 \text{ lb.}$$

The work done by the water is,

$$998.4 \times 10 = 9984 \text{ ft.-lb.}$$

One horse-power is equal to 33,000 ft.-lb. per minute, or 550 ft.-lb. per second; allowing 30 per cent. for friction, the power available is,

$$\frac{9984\,(1-0.30)}{550} = 12.7 \text{ h.p.}$$

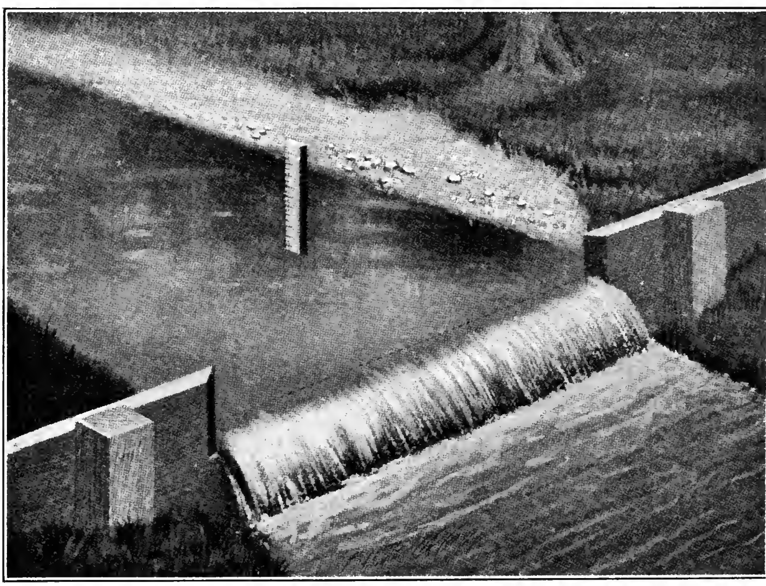


FIG. 178.

Another method for finding the quantity of water available in a stream, called the weir dam method is illustrated in Figs. 178. A notch is cut in a thick board placed at some point in the stream.

The length of the notch should be less than two-thirds the width of the board. The bottom of the notch is called the crest of the weir, and the depth of the water at that place should be more than three times the depth of the water flowing over the weir. The crest of the weir should be perfectly level and should be beveled on the down-stream side. The edges of the notch should also be beveled on the same side. In the stream back of the weir, and at a distance somewhat greater than the length of the notch, a stake is driven level with the bottom of the notch or crest of the weir. When the water is flowing over the weir, measure the height of water above the top of the stake. If this height in feet is called H and the width of the notch in feet B, the quantity of water Q flowing through the stream, in cubic feet per second, can be determined by the formula:

$$Q = 3.33\ B\ H\sqrt{H}$$

As an illustration, if the width of the notch is 4 ft. and the depth of water on the weir is 12 in. the quantity of water available per second is:

$$Q = 3.33 \text{ x } 4 \times \frac{12}{12} \sqrt{\frac{12}{12}} = 13.32 \text{ cu. ft.}$$

Since 1 cu. ft. of water = 7.48 gallons, the quantity of water delivered in gallons is,

$$13.32 \times 7.48 = 99.6 \text{ gallons.}$$

Types of Water Motors.—The water motors mostly used at the present time are water wheels, which are made to revolve either by the weight of water falling from a higher to a lower level, or by the dynamic pressure which is produced by changes in the direction and velocity of flowing water.

Reciprocating water motors are used to a limited extent for special purposes. Any steam engine with slight modifications can be used as a reciprocating water motor, but would run at slow speed on account of the incompressibility of water.

Overshot, Undershot and Breast Wheels.—The earlier water motors derived their power from the weight of water acting on vanes placed around the rim of a wheel.

Of these the overshot wheel receives its power from the weight of water carried by buckets on the circumference of a wheel, the water entering the buckets near the top of the wheel and being discharged near the bottom (Fig. 179). A wheel of this type can

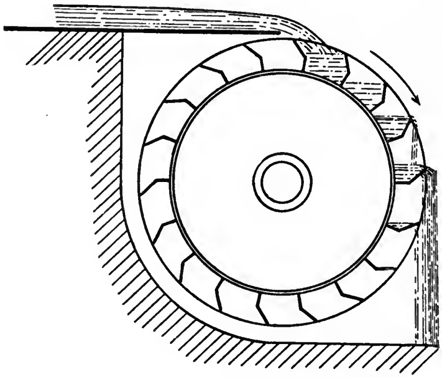


Fig. 179.

be easily constructed by inserting between two wooden discs a number of buckets, made like V-shaped troughs (Fig. 179), and putting a wooden or metal shaft at the center of the discs. Water is supplied from an open trough near the top of the wheel.

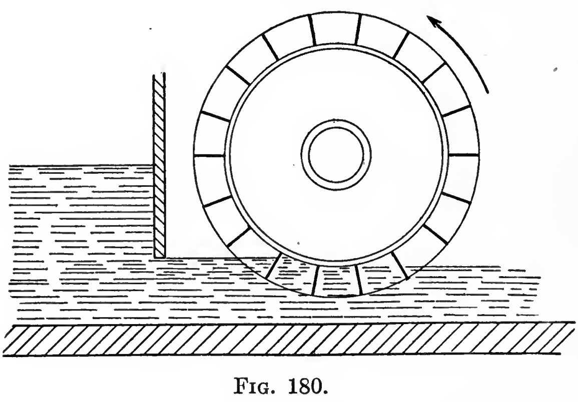


Fig. 180.

Motors of this character can be built to operate on falls as low as 4 ft. and will supply from 3 to 50 h.p., depending on the head of the fall and on the quantity of water available.

The undershot wheel is propelled by water passing beneath it in a direction nearly horizontal, which impinges on vanes carried by the wheel. Such wheels have been used to some extent for irrigation work. Some of the undershot wheels have straight flat projections for vanes (Fig. 180), but the more efficient wheels are built with curved vanes. Such motors are suitable for very low falls, provided the velocity of the water is great.

The breast wheel (Fig. 181) receives water at or near the level of its axis, but is otherwise quite similar in its action to the overshot wheel. Breast wheels are provided with either radial vanes, or with vanes slightly curved backward near the circumference.

All these wheels are very bulky for the power developed, as compared with the more modern types of water motors.

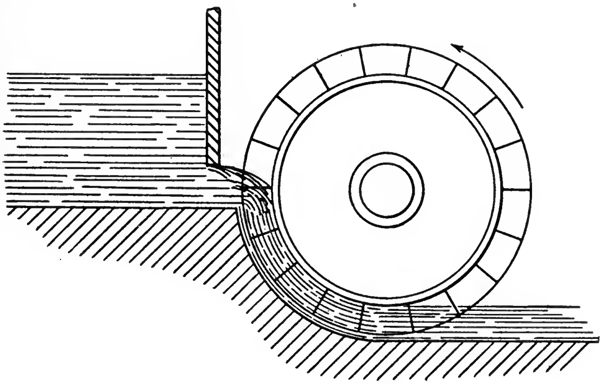


Fig. 181.

Impulse Water Motors.—Impulse water motors are provided with buckets or cups around the circumference of a wheel, which are acted upon by a jet of water issuing from a nozzle.

Among impulse water motors, the Pelton wheel illustrated in Fig. 182 is used to a considerable extent in the United States. It consists of a series of cups or buckets *B* placed at equal intervals around the circumference of an iron wheel. The characteristic feature of the Pelton motor is the shape of the buckets. These are made in the form of two half cylinders with closed ends, joined together at the center by a straight thin rib. The power is derived from the pressure of a head of water supplied by a pipe which discharges upon the buckets of the wheel. The water from the nozzle *N* striking the rib, divides

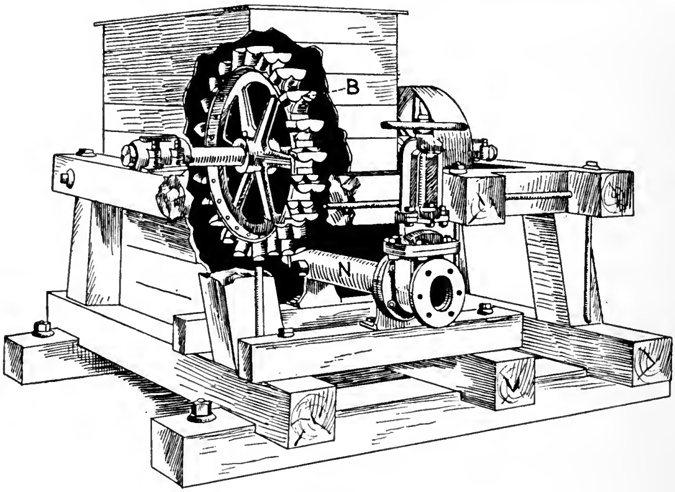


Fig. 182.

into two streams, one going into each half cylinder and exerting a pressure on the curved surfaces of the buckets. The Pelton water motor is usually furnished with two nozzle tips of dif-

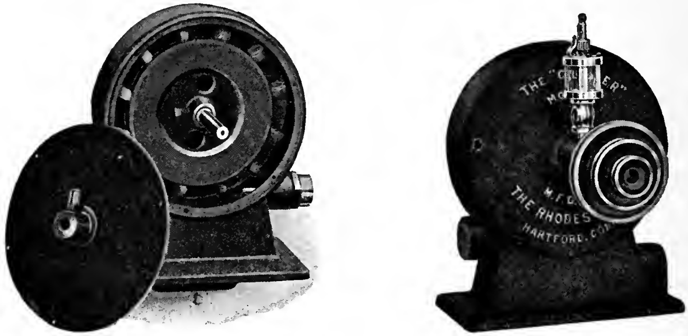


Fig. 183.

ferent diameters. By changing the tip, the size of the stream on the wheel is altered and a great variation in power may be obtained.

Pelton water motors can be secured in very small sizes under 1 h.p. and up to several hundred horse-power. The efficiency of this type of motor is greatest at high heads, but in small sizes it will be found as efficient as most water motors, even for heads as low as 15 ft.

Another type of water motor illustrated in Fig. 183 is made in sizes less than 1/2 h.p. and is used for running washing machines,

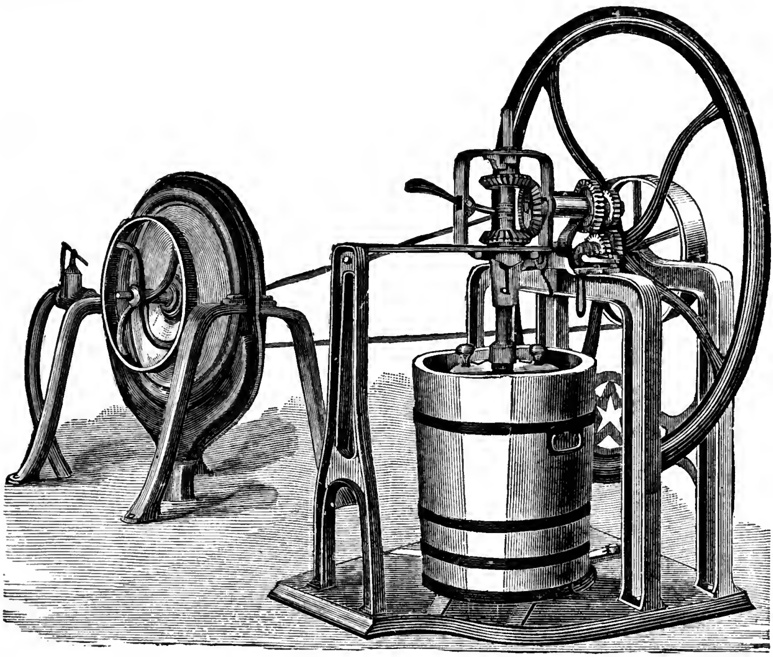


FIG. 184.—Water motor driving an ice cream freezer.

sewing machines, grindstones, fans, small feed grinders, and for other purposes requiring little power.

An impulse water motor can be operated from city water mains or from an independent stream.

Some of the applications of water motors are illustrated in Figs. 184 and 185.

Water Turbines.—A water turbine is a water motor which is made up of a number of stationary and movable curved pipes. It consists of the following parts:

1. A gate by means of which the supply of water to the turbine is regulated.

2. A guiding element consisting of stationary blades, the function of which is to deliver the water to the revolving element in the proper direction and with the proper velocity.

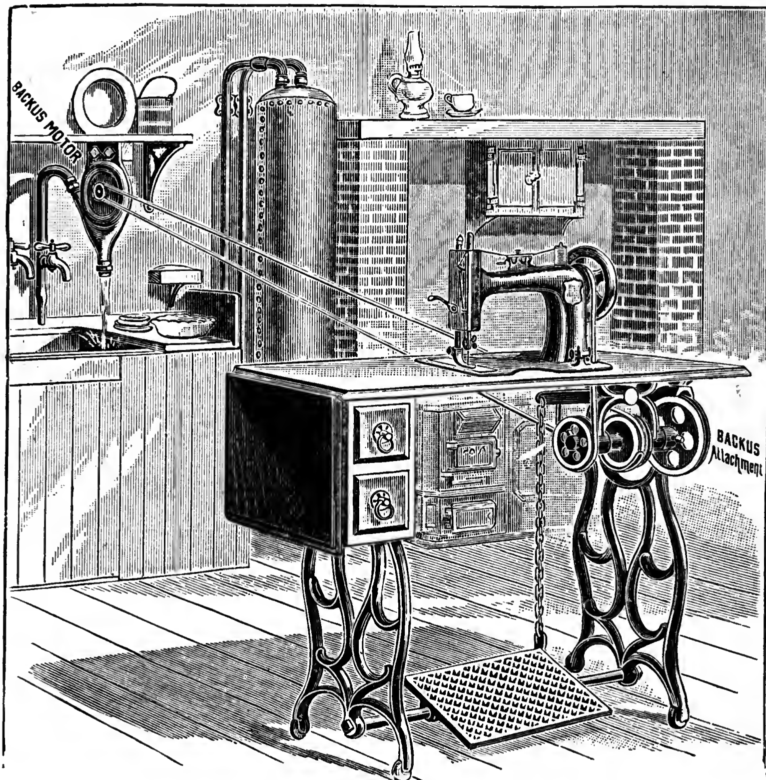


Fig. 185.—Water motor driving a sewing machine.

3. A revolving element or rotor, consisting of vanes or buckets which are arranged in any one of several different ways around the axis of the motor.

Water turbines are divided into radial outward flow, radial inward flow and mixed flow types.

In the radial outward-flow turbine the water is received at the center and is delivered at the periphery of the revolving buckets.

In the radial inward-flow types the stationary or guiding element is located on the outside of the revolving part, and the water flows from the rim toward the center.

The advantages of turbines over impulse wheels lie in the fact that a turbine can be utilized for very low falls. The turbines illustrated in Figs. 186 to 188 can be used on falls as low as 4 ft.

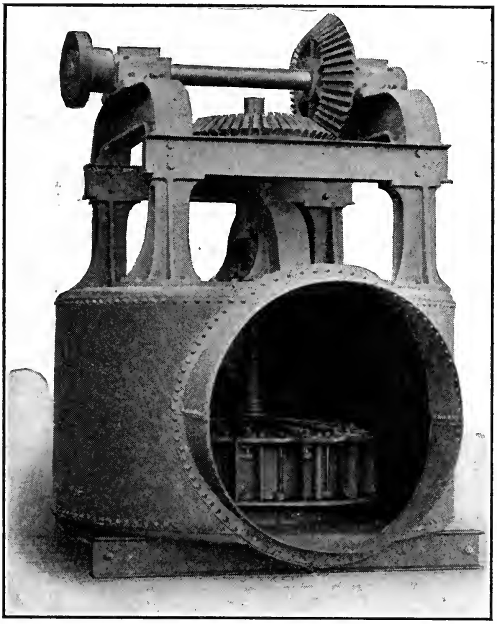


Fig. 186.

and will develop about 3 h.p. with a water supply of about 500 cu. ft. per minute.

The general appearance of a water-power installation with vertical turbines is shown in Fig. 187.

The application of turbines for the driving of centrifugal pumps is illustrated in Fig. 188.

The Hydraulic Ram.—The hydraulic ram combines in one simple machine a motor and a pump. It is probably the simplest and most economical method for supplying water for the farmhouse, the feed-yard, barn and the dairy where conditions are favorable. It can also be used to advantage, under certain conditions, for irrigating small tracts of land.

Hydraulic rams are low in first cost and inexpensive to operate. They are not economical in water, as a large amount of water must be wasted in comparison with the work done.

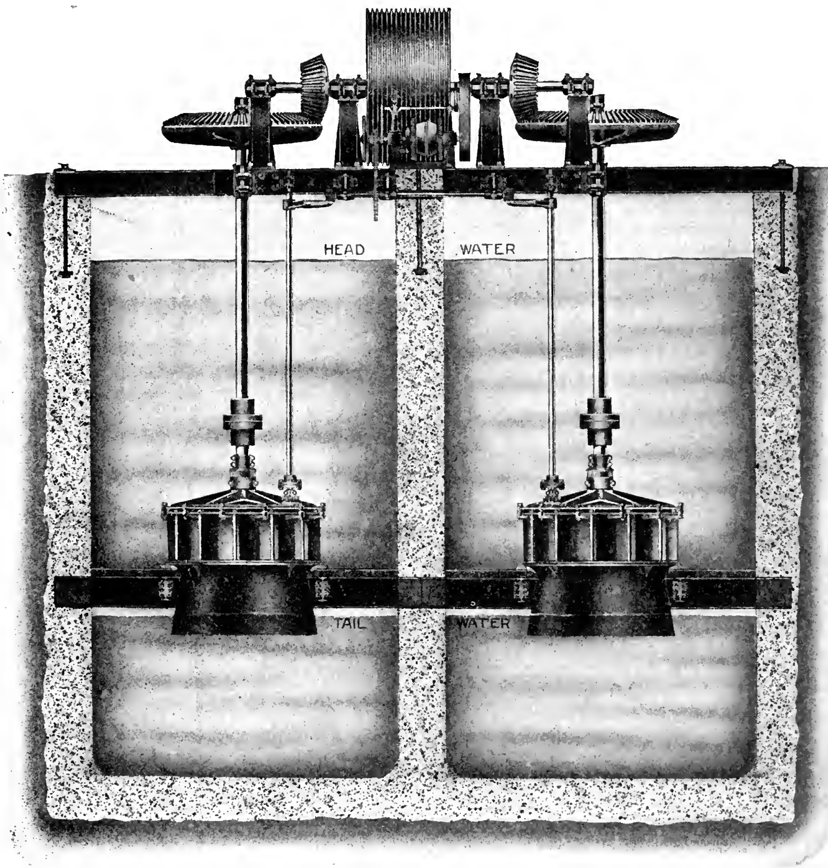


Fig. 187.—Morgan-Smith turbines.

The working of the hydraulic ram depends on the fact that the momentum of a large quantity of water falling through a small height is capable of lifting a small quantity of water to a considerable elevation.

A section of a hydraulic ram is shown in Fig. 189. It consists of a working valve V, a check valve D, an air chamber C, a drive

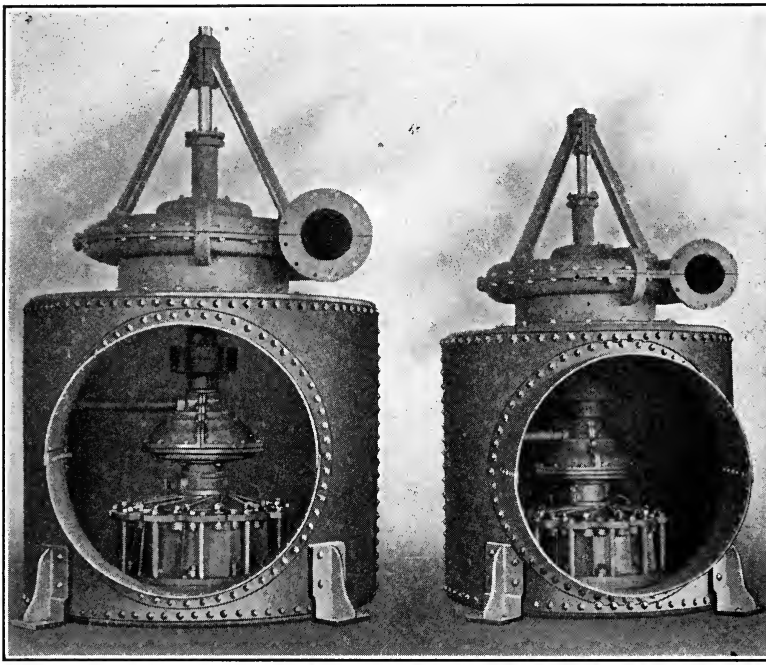


Fig. 188.

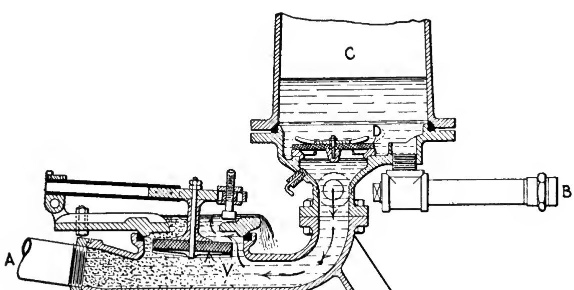


Fig. 189.

pipe A which supplies water to the ram, and a delivery pipe B which carries the water to the place where it is utilized.

The ram is located at a place where a fall of 2 to 10 ft. can be obtained. The water from the source enters the drive pipe (A in Fig. 189) and flows through the working valve V. The velocity of water in this pipe increases and when a certain velocity is reached, the pressure of the water on the under side of valve V is sufficient to close it abruptly. The flow of the water through the working valve being interrupted, the pressure increases and causes the check valve D under the air chamber C to open, and

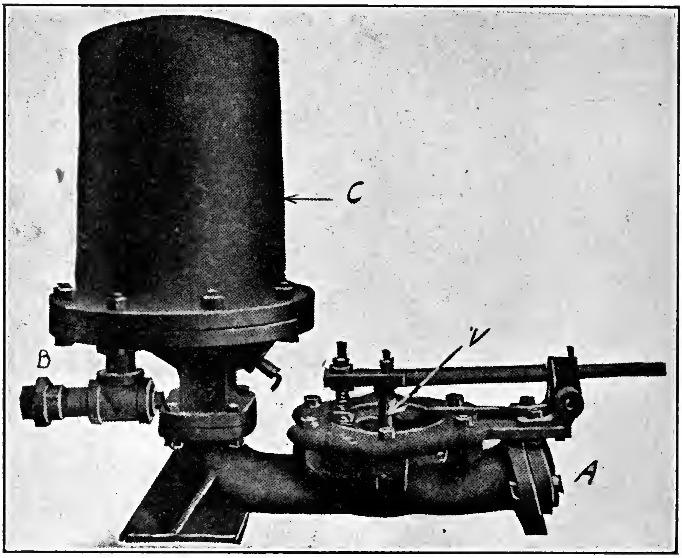


FIG. 190.

a part of the water is forced in the air chamber compressing the air in that chamber. The velocity of the water in the drive pipe having been arrested, a recoil or ramming takes place, the pressure in the space below air chamber check valve D is reduced, thus closing the check valve D and allowing the working valve to open. The operations are then repeated. The delivery pipe to the storage tank at the higher elevation is attached to the air chamber below the water level. The air under compression in the air chamber forces the water in a steady stream through the delivery pipe B and to the storage tank. Hydraulic rams are also provided with a sniffing valve, not shown in the figure, the function of which is to replace any air in the air chamber, lost by being dissolved in the water.

A hydraulic ram is illustrated in Fig. 190. A is the drive pipe, B the discharge pipe, C the air chamber and V the working valve.

CHAPTER IX

WINDMILLS

Types of Windmills.—The windmill is a motor which converts the kinetic energy of the wind into useful work.

Some of the earlier windmills were constructed with sails which consisted of wooden frames, the broad sides of which were covered with cloth. These sails were turned by the wind in horizontal or vertical planes. One of these mills, the Dutch type, is illustrated in Fig. 191. As the direction of the wind changed, the entire wheel-house, including shafting and machinery, was rotated on a pivot so as to bring the wheel to face up to the wind. This limited the size of the mill. In the latter types of the Dutch mill, only the upper part of the wheel-house was rotated. These mills were governed by varying the extent of the sail surface exposed to the wind by hand, while the wheel was at rest. The Dutch types of wooden mills are powerful, but bulky and expensive. They are but little used in this country at the present time.

FIG. 191.—Dutch windmill.

The American mill is made up of a great number of narrow blades or fans. This means a mill of smaller weight and less bulk than the Dutch mill of the same power.

Windmills may be classified as pumping and power windmills. The pumping windmill gives a reciprocating motion to a vertical rod suitable for operating a pump, while the power windmill gives rotary motion to a shaft through a train of gears.

The wheel and rudder of American windmills are constructed either of wood or of steel. The best steel windmills are galvanized for protection from rust.

Windmills are designated by the diameter of the wind wheel. Thus the so-called 15-ft. mill has a wheel 15 ft. in diameter.

American windmills are built either as direct stroke or as back-geared. In the case of the direct stroke windmill the main shaft carries a crank which is attached to the pump rod by a connecting rod, commonly called the pitman, there being no speed reducing gears. In this type, the pump makes one complete stroke for each revolution of the wind wheel. Geared mills are back-geared, so that the pump makes one stroke for every three or five revolutions of the wind wheel. The back-geared mill will develop more power than the direct-connected mill for a wind wheel of the same diameter.

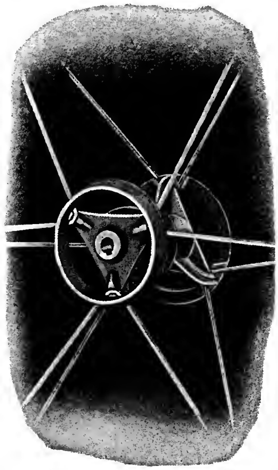


Fig. 192.—Hub of aermotor wind wheel.

Principal Parts of a Windmill.—The principal parts of a windmill are:

1. A wind wheel which receives the kinetic energy of the wind. This wheel is carried upon the main shaft.
2. A rudder or vane which steers the wheel against the wind.
3. A governor, which regulates the speed of the wind wheel.
4. Gearing.
5. A brake which holds the wheel stationary when out of the wind.
6. Main casting which supports governor, gearing and brake. This with the parts which it supports is called the mill head.
7. A tower which is a support for the mill. The tower should be tall enough to raise the wheel sufficiently high above all obstructions, such as trees, houses, etc., so that the wheel will receive a steady breeze.

The Wind Wheel.—The wind wheel (Fig. 193) is that part of the mill which derives the energy from the wind.

The hub of the wheel either consists of two separate wheel spiders (Fig. 192) keyed to the main shaft, or it is constructed as a solid casting with the wheel spiders at either end.

The arms or spokes of the wheel (S in Fig. 193) are attached to the wheel spiders (P) and extend outward to the rim R. The spokes are usually of rectangular or circular cross-section, but some manufacturers use steel angles.

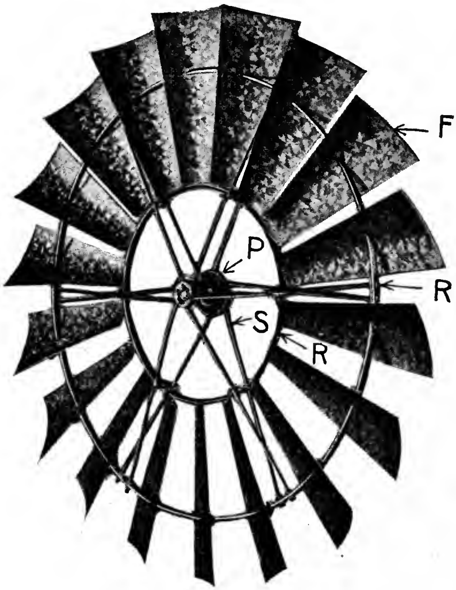


Fig. 193.

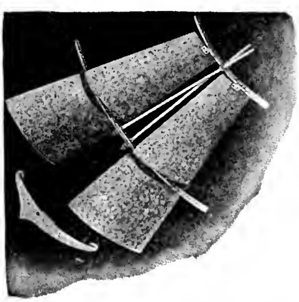


Fig. 194.—Fans of aermotor windmill.

The rims are placed one near the inner ends of the fans F, and the other either a little beyond the center or near the outer ends of the fans. The rims are made either of strap steel or of angle steel.

The fans (Figs. 193 and 194) are so curved that the wind on leaving one fan will not strike upon the back of the next. The spacing of the fans is such that the wind passes through freely and all parts of the wheel must be so designed as to offer the least resistance to the wind. The fans are fastened to the rims by brackets and the various sections of fans and rims are riveted together.

Figure 195 shows a Samson wheel with strap steel spokes and hollow hub.

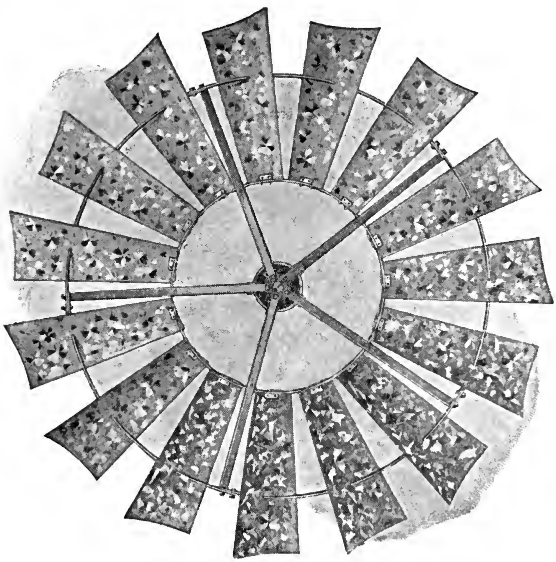


FIG. 195.—Samson wheel.

The general construction of a wooden wind wheel is similar to that of the steel wheel, except that the spokes, rims and fans are of wood. The rims are made either straight from spoke to spoke or are bent in a manner similar to that of steel mills. A section of a wooden wind wheel is illustrated in Fig. 196. The wooden wind wheel is made up of six or more sections, each section consisting of 15 or more slats.

The Rudder or Vane.—Most windmills are provided with some form of rudder or vane for keeping the wheel in the direction of the wind. In some windmills no rudder is employed, and the pressure of the wheel on the wind wheel is relied upon to bring the wheel in the right direction. Windmills without rudders are provided with folding wheel fans and have a weighted ball which performs the function of a rudder and opens the wheel when the wind is greater than the load. Then some of the larger windmills without rudders are provided with a small side

Fig. 196.

wheel which is set perpendicular to the wind wheel, and turns the wind wheel into the proper direction by means of gearing.

The rudder is built either of steel (Fig. 197) or of wood (Fig. 198).

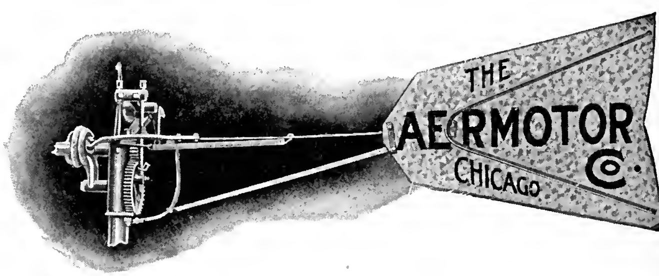


Fig. 197.—Steel rudder.

It is often desired to throw the wind wheel out of action. This in the case of the folding wheel is accomplished from the ground level by a wire or rod which extends up through the tower and connects with a system of levers which tip the sections of the wheel. The solid wheel is thrown out of action either by pulling it around parallel with the vane, so that its edge faces the wind, or by pulling the vanes parallel to the wind.

The Governor.—The function of a governor is to regulate the speed of the wind wheel.

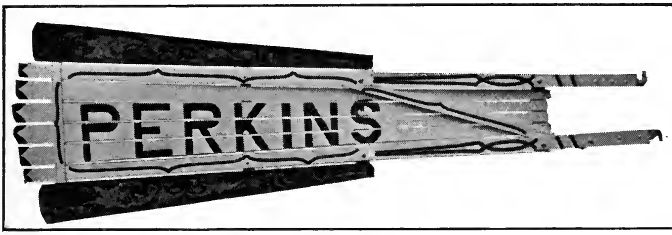


Fig. 198.

In some windmills the governor consists of a coiled spring, one end of which engages with the rudder and the other with the mill head. When the wind pressure becomes too great, the wheel will swing so as to expose less surface to the wind.

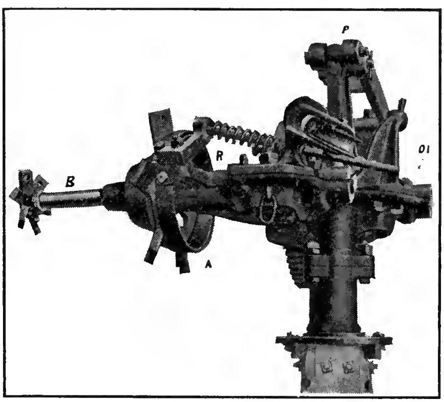


Fig. 199.

To assist in governing, some mills are provided with a side vane.

In the case of folding wheel mills the angle of the fans is changed, by a system of weights and levers, according to the intensity of the wind.

Most windmills are provided with a "pull-out reel," which consists of a ratchet and windlass for throwing the wind wheel out of action. When the ratchet is released the wind wheel is thrown into correct position by the rudder and governor. Some windmills use a lever instead of a ratchet and windlass for the same purpose.

Windmill Gearing.—The gearing of a direct-stroke windmill is illustrated in Fig. 199. A is the inner wheel spider which is attached to the main shaft B. A crank on the main shaft is connected with the rocker arm R by means of a pitman. The pump rod is fastened directly to the outer end of the rocker arm. A chain is attached to the two pulleys O and P and connects with the pull-out reel explained in the last section.

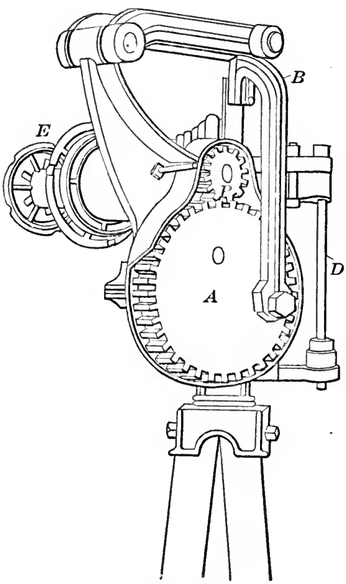


Fig. 200.

One simple form of a back-geared mill mechanism is given in Fig. 200. E represents the hub of the wind wheel. The pinion P is carried on the main shaft and meshes with a large gear A on a counter-shaft. The center of the gear A is placed to one side of the upper end of the connecting rod or pitman B, so that it requires more than half of a revolution to raise the pump rod and less than half of a revolution to lower it. Thus a quick return motion is obtained, the pump rod descending more rapidly than it rises. This is advantageous in that little power is required on the down stroke, there being no water raised and the weight of the plunger, pump pole and pump rod being sufficient to produce that stroke. The slow motion on the up stroke enables the mechanism to carry the load with the least strain. In this mechanism D is a hinge for attaching the rudder or vane.

The difference in construction between the gearing for pump-

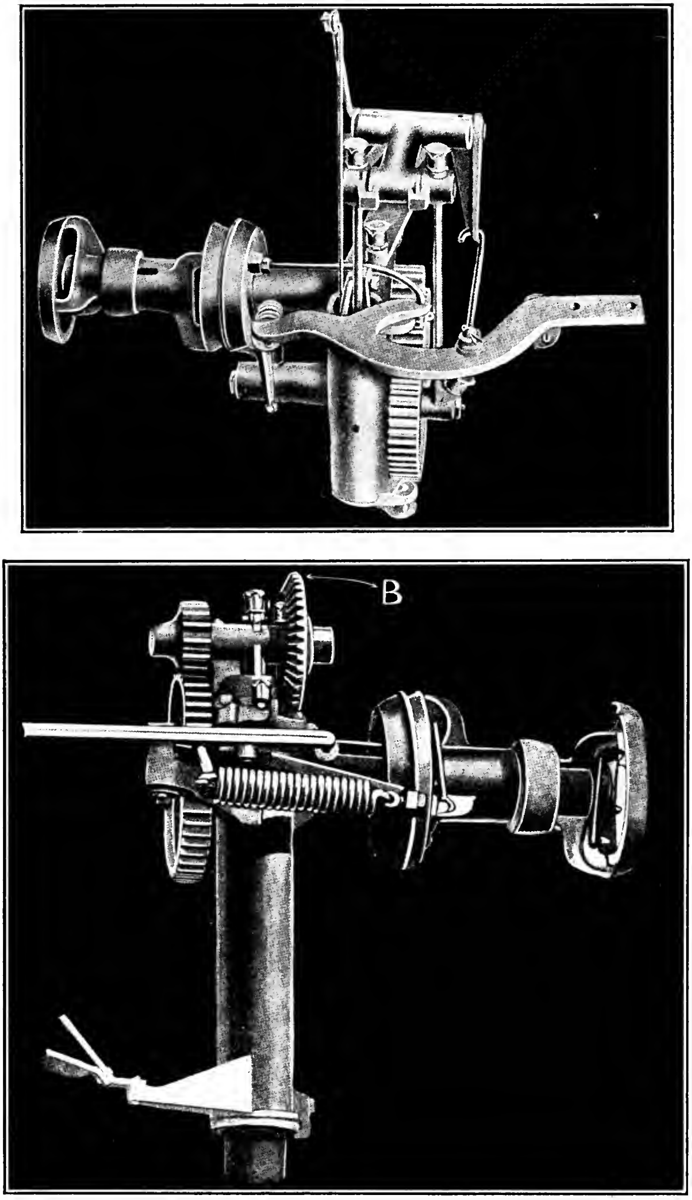


FIG. 201.

ing and power windmills is in the addition of a bevel gear B (Fig. 201) which meshes with another bevel gear on the power shaft.

All windmills should be provided with some form of buffer to protect the rudder and other parts from sudden shocks when the windmill is thrown out of gear. The buffer is usually constructed in the form of a helical steel spring placed upon the rudder rail near the hinge.

Windmill Brake.—Nearly all windmills are provided with an automatic brake, which holds the wheel stationary when out of the wind. The brake is a flexible steel band which encircles about three-fourths of the flange on the hub of the wind wheel and holds it stationary when out of gear. The brake is applied by a lever as soon as the windmill is turned out of gear.

Towers.—Windmill towers are constructed either of wood or of steel.

There are a great many different kinds of wooden towers as they are often "home-made." Four 4-in. by 4-in. or 6-in. by 6-in. timbers, depending on the size of the tower, are most commonly employed for the corner posts. They are spread about 8 or 10 ft. at the bottom and are brought together at the top and fastened to a cast-iron cap, usually provided by the manufacturer. A platform 2 or 3 ft. square should be provided directly below the wind wheel for the purpose of facilitating oiling, inspection and repairing. The tower ends of the corner posts are bolted to anchor posts which are set about 6 ft. in the ground with cross pieces bolted to the lower end to form a better foundation.

Steel windmill towers are built with either three or four posts and should always be galvanized and not painted. A tower supported on four posts (Fig. 202) is protected from a wind in either direction. The three-post tower (Fig. 203) is somewhat cheaper than the four-post tower, and has the additional advantages for localities where the ground is soft, in that the tower always stands firm and rigid, and is not affected by unequal settling of anchor posts. A three-post tower when properly braced is also stiffer and stronger than a four-post tower.

The corner posts of a steel tower are usually of angle steel, but some are of gas pipe. The cross girts are of angle steel and

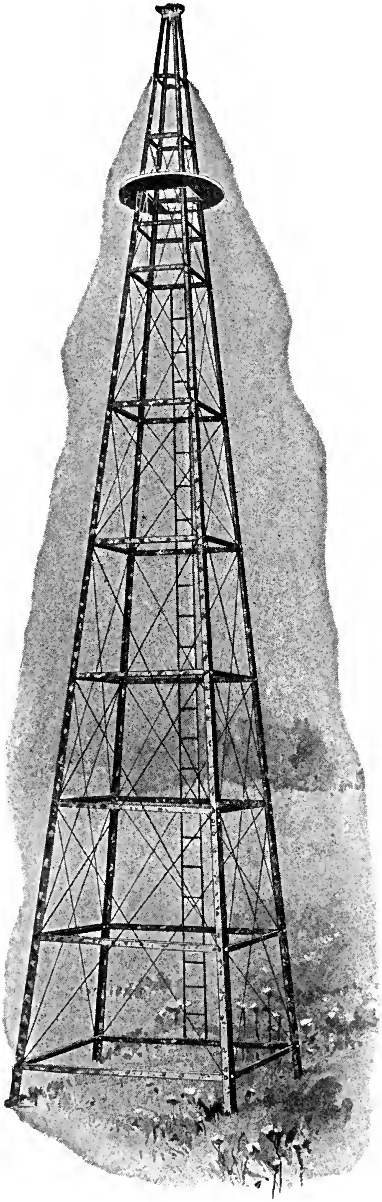


FIG. 202.—Four-post tower.

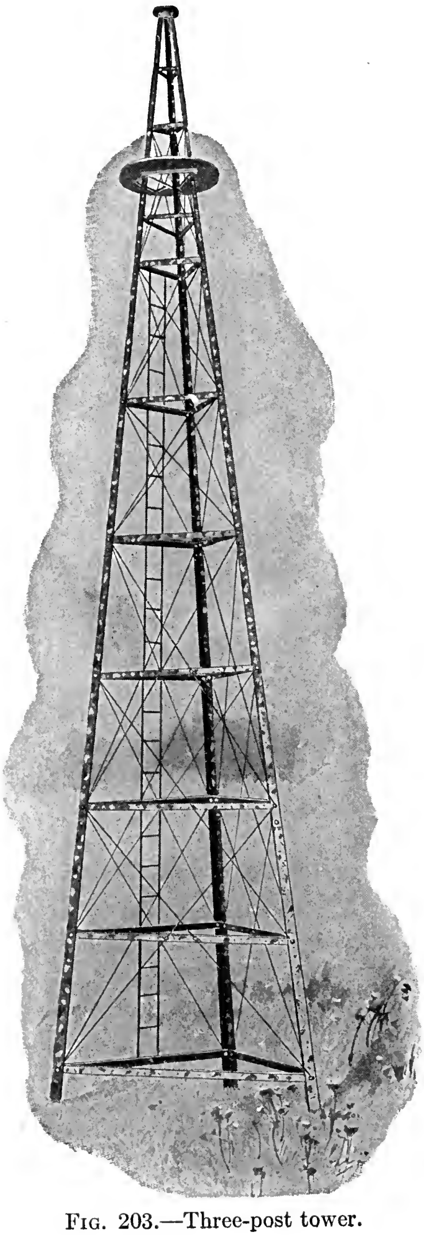


FIG. 203.—Three-post tower.

the braces may be of angle steel, rods, or wire cable. The anchor posts are about 6 ft. long and of the same material as the corner posts, with anchor plates attached at the lower end.

The method of fastening the corner posts of three- and four-post towers is shown in Fig. 204. The posts are beveled, notched and are held together by clamps and bolts.

The tower in Fig. 205 has the lower braces of angle steel and the other braces of rods. Twisted wire cable braces are shown in Fig. 206.

Method of Erecting Windmills.—A windmill is erected either by building it up in position piece by piece, or it is assembled on the ground and then raised into position. The method of raising a windmill from the ground is illustrated in Fig. 207.

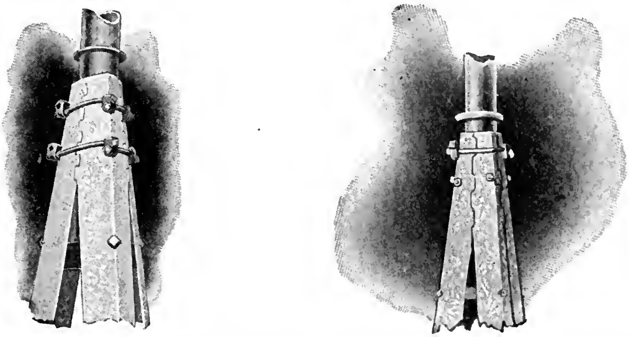


FIG. 204.—Method of fastening corner posts of 3-post and 4-post aermotor towers.

After the holes for the anchor posts are dug, the anchor posts are placed loosely in them. In raising towers over 30 ft. in height, the lower portion should be reinforced by placing timbers in the tower (Fig. 207). A beam of wood is then placed across the lower ends of the legs, and stakes are driven at each end, in order to prevent the tower from sliding when it is being raised. A strong rope is attached to the tower near the platform and to a block and tackle a little beyond the lower end of the tower. Another block is made fast to some stakes driven at a distance of one and one-half times the length of the tower from the lower end of the tower. Shear poles about one-half the length of

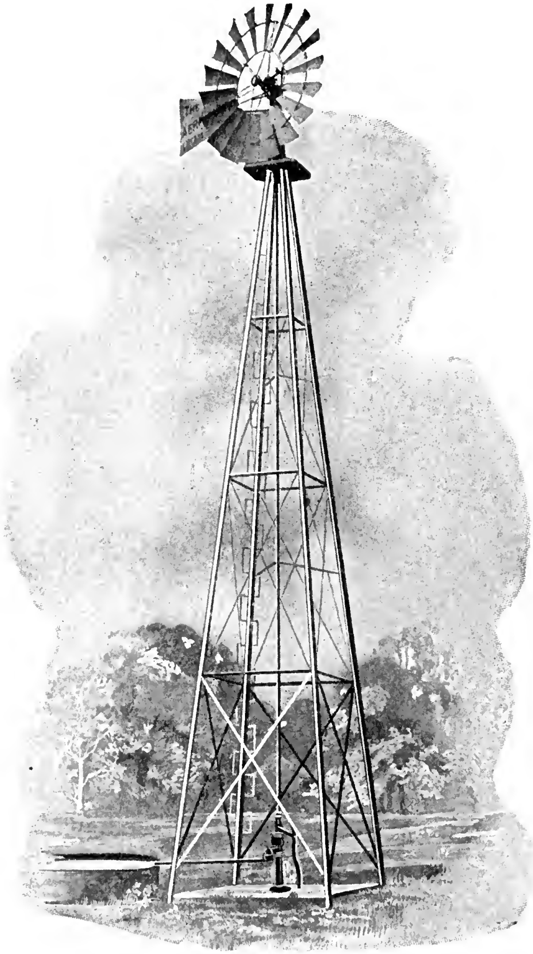


FIG. 205.—Tower of aermotor windmill.

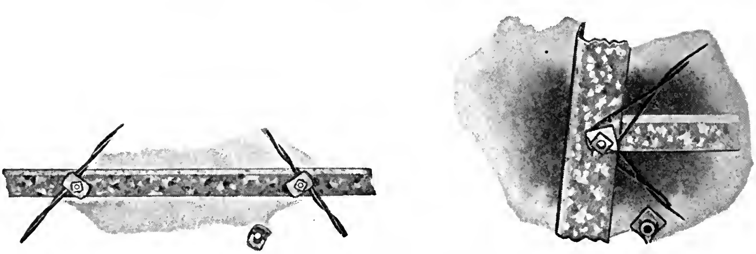


FIG. 206.—Twisted wire braces.

the tower are then placed under the rope near the lower end of the tower. Stakes are driven at each side of the upper end of the tower and the tower is pulled into position by a

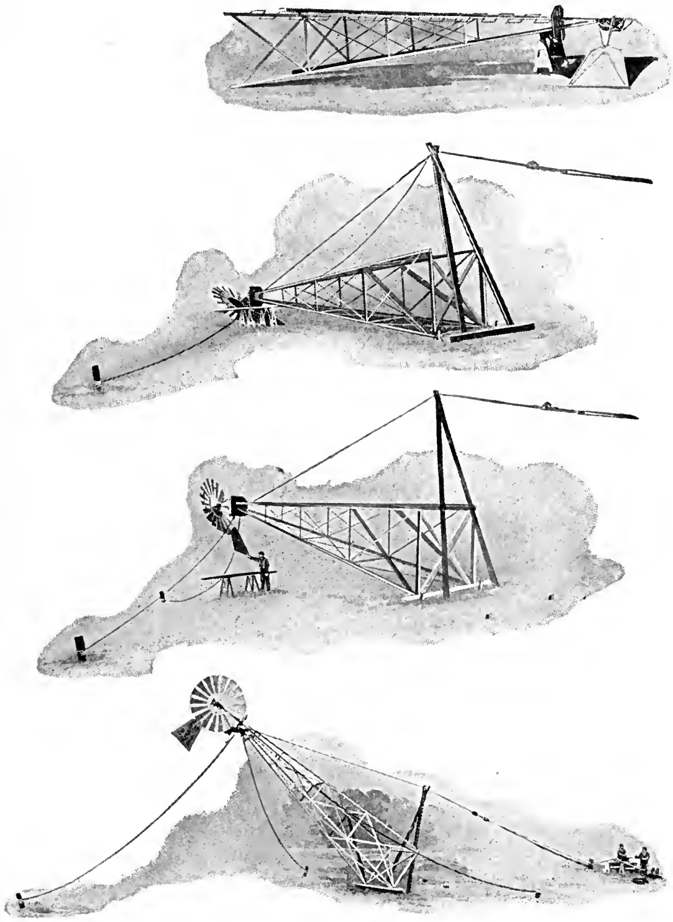


FIG. 207.—Method of raising windmill from the ground.

traction engine, team, or windlass. Several men can usually raise a small tower by pulling directly on the tackle rope.

After the tower is in position it should be leveled with a plumb bob, before the pump rod is put in place. All braces must be evenly tightened.

The anchor posts are then bolted to the corner posts and the holes filled in. Loose stones are often placed below and above the anchor plate. For best results a concrete base should be used. When using loose stones, it is desirable that the anchor plates should rest on cap stones.

Care of Windmills.—A windmill requires some care if long and good service is expected.

When first erected it should be carefully examined every few days for loose bolts and bearings.

All bearings should be kept well lubricated and brasses tight. If anchor posts work loose they should be reset. It is always well to shut down a windmill during a heavy storm.

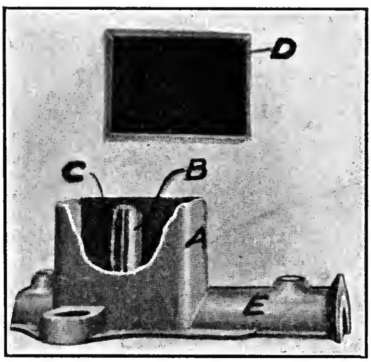


Fig. 208.

Windmills may be lubricated by means of oil cups, the oil being held in place by waste. With the ordinary oil cups a windmill would have to be lubricated every two or three days if it is running steady. To reduce the necessity of frequent lubrication, some form of self-feed oil cup as illustrated in Fig. 208 is used. This consists of a large oil cup A with a tube B extending nearly to the top of the oil cup. A twisted wire wick C passes from the bottom of the oil cup into the tube. The oil from the cup follows the wicking into the tube and lubricates the bearing E which is at the bottom of the tube. D is a lid for the oil cup.

Power of Windmills.—The power delivered by a windmill depends on the velocity of the wind, on the size and construction of the wheel, on the amount of power lost in friction and on the density of the air.

It has been found that an average wind velocity of 6 miles per hour is required to drive a windmill. The average velocity of the wind in the United States varies from 4.2 to 16 miles per hour. The velocity in most localities is great enough to operate a mill about eight hours per day.

The power developed by a windmill with winds of average intensity will vary from 1/8 h.p. for a 6-ft. wind wheel to about 1 h.p. for a 16-ft. wind wheel. With strong winds and with large wheels, windmills will develop as much as 4 h.p.

The angle and spacing of the wind wheel fans affect the power delivered by a windmill. Then the quality and condition of the gearing and bearings determine the actual power available for utilization either at the pump or power shaft.

The density of the air affects the pressure of the wind on the wind wheel. Thus the higher the altitude the lighter is the air and the less power is developed with a wind of a certain velocity.

Uses of Windmills.—The main use of windmills is for pumping water for domestic use and for stock. When used in pumping water for irrigation, a storage tank of large capacity should be provided, sufficient for several days use in case of calm weather.

For watering stock on small farms and for domestic use on the farm, the windmill is the cheapest and best form of motor. It requires but little attention. One-half hour per week devoted to oiling and inspection will keep the mill in good condition.

A windmill cannot be used for heavy work on the farm, but can drive small feed grinders, grindstones, corn shellers, feed cutters, wood saws, churns or any other machine requiring little power.

In general the windmill is suitable for work requiring but little power, which will admit of suspension during calm weather.

CHAPTER X

ELECTRIC MOTORS, DYNAMOS AND BATTERIES

Before considering the various types of electric motors and their applications, the fundamentals of electricity and of dynamo electric machinery will be taken up.

Action of Electricity.—The action of electricity in a dynamo is analogous to that of water pumped from a lower to a higher level. The function of a pump in forcing water through pipes is well known. The pump exerts a pressure on the water. If the pressure exerted by the pump is doubled, the quantity of water handled by the pump will also be doubled, if the friction of the water through the pipe remains the same. It is also well known that the resistance offered to the flow of water through pipes increases with the length of the pipe. Also by increasing the size of the pipe the resistance is decreased.

The dynamo in the electric power plant performs a function similar to the pump. It generates electrical pressure in order to send electricity through the wires which correspond to pipes. The resistance offered by the wire to the flow of electricity is analogous to that offered by the water pipe to the flow of water. The quantity of electricity delivered to the circuit, which may consist of motors, lamps or other appliances using electricity, corresponds to the amount of water delivered by the pump to an overhead tank or pipe from which water motors or other appliances requiring water under pressure can be operated.

Units of Electricity.—The pound is the unit of water pressure, while the unit of electricity is the volt. The amount of water flowing through a pipe is measured in gallons per minute, the quantity of electricity flowing through a wire in amperes. The resistance which a wire offers to the flow of electricity is measured in ohms.

The unit of electrical power is the watt, a watt being the product of a volt and ampere. This is evident from the water analogy. The power available in a certain weight of water depends on the head, or distance the water is allowed to fall. Similarly the power available at the terminals of a dynamo is the product of the quantity of electricity in amperes and the electrical pressure head in volts.

As an illustration, the power available at the terminals of a dynamo delivering 60 amperes at 110 volts is,

$$\text{Power in watts} = 60 \times 110 = 6600$$

Dynamos are usually rated in kilowatts (kw.), a kilowatt being 1000 watts. Electric motors are rated in electrical horse-power, an electrical horse-power being equal to 746 watts. The relation between the kilowatt and the electrical horse-power is $\frac{1000}{746} = 1\,1/3$.

Thus an electric motor operating on a 220-volt circuit and requiring 30 amperes has delivered to it,

$$\frac{220 \times 30}{746} = 8.85 \text{ electrical horse-power.}$$

If the efficiency of the motor is 80 per cent., the available power at the motor shaft is $8.85 \times 0.80 = 7.08$ brake horse-power.

Ohm's Law.—The law expressing the relation between the volt, the ampere and the ohm is of great value in electrical calculations. It is called Ohm's law and is expressed by the statement that

$$\text{The current in amperes} = \frac{\text{Pressure in Volts}}{\text{Resistance in Ohms.}}$$

Expressing the current by the symbol I, the volt by E and the resistance by R

$$I = \frac{E}{R}$$

As an illustration, an ordinary 16 candle-power carbon lamp operating on a 110-volt circuit offers a resistance of 220 ohms. How much current will be required to operate the lamp?

Applying Ohm's law,—

$$I = \frac{E}{R} = \frac{110 \text{ Volts}}{220 \text{ Ohms}} = \frac{1}{2} \text{ amperes.}$$

The power required to operate the lamp is

$$110 \times \frac{1}{2} = 55 \text{ watts.}$$

Considering no losses in the engine, dynamo and lines, the number of 16 candle-power carbon lamps which can be operated by a dynamo driven from 1 h.-p. engine is:

$$\frac{746}{55} = 13.56 \text{ lamps.}$$

Due to line losses and to losses in the generator, it is customary to figure about ten 16 candle-power carbon filament lamps per engine horse-power.

Table 7 gives the current consumption of carbon filament lamps of various candle-powers.

TABLE 7.—CURRENT CONSUMED BY CARBON FILAMENT INCANDESCENT LAMPS OF VARIOUS CANDLE-POWERS

Voltage	8 c.p.	10 c.p.	16 c.p.	20 c.p.	24 c.p.	32 c.p.	50 c.p.
52	0.55	0.69	1.11	1.38	1.66	2.22	3.46
104	0.28	0.35	0.55	0.69	0.83	1.11	1.73
110	0.26	0.33	0.52	0.65	0.78	1.05	1.64
220	0.15	0.18	0.29	0.36	0.44	0.58	0.91

Wires for Conductors of Electricity.—The resistance which a wire offers to the flow of electricity depends on its cross-section and on the material from which it is made. Silver when pure is considered to be the best conductor. Copper is very nearly as good a conductor as silver, and, being much cheaper, it is used in nearly all cases for the distribution of electricity.

Copper wire is sometimes used bare, but in most cases it is covered with a material called insulation, to prevent the transfer of electricity to surrounding substances. The insulation used on wire is either rubber or some weather-proof substance.

Copper wires are designated either by the Brown and Sharpe wire gage (B. & S. gage) or by their cross-section in circular mills. A circular mill is a circle 1/1000 in. in diameter. The designation of wire by the B. & S. gage is more common for small wires. This gage is constructed so that the numbers decrease as the size of the wire increases. Thus a No. 10 B. & S. wire is smaller than a No. 9 and larger than a No. 11.

The current-carrying capacities in amperes of various sizes of rubber-covered and weather-proof wire is given in Table 8.

TABLE 8

Size of copper wire		Current-carrying rubber-covered wire	Capacity in amperes, weather-proof wire
B. & S. gage	Circ. mills		
18	1,624	3	5
16	2,583	6	8
14	4,107	12	16
12	6,530	17	23
10	10,380	24	32
8	16,510	33	46
6	26,250	46	65
5	33,100	54	77
4	41,740	65	92
3	52,630	76	110
2	66,370	90	131
1	83,690	107	156
0	105,500	127	185
00	133,100	150	220
000	167,800	177	262
0000	211,600	210	312

The sizes of wire in the tables are given in terms of the B. & S. gage as well as in circular mills.

Electrical Batteries.—Batteries are used mainly in places where the current requirement is small, as in connection with the ignition system of internal combustion engines, also for operating telephones, telegraphs, electric bells, etc.

Batteries can be called chemical generators of electricity, and are of two types. One type, called the primary battery, generates electrical current by means of direct chemical action between certain substances. Another type is called a secondary battery or storage battery, requires charging with electricity from some outside electric source before it will generate electrical energy. The outside current acting on the substances within the battery changes their chemical properties to such an extent that the battery is able to deliver current when connected to a circuit. After storage batteries furnish current to a circuit for a certain length of time, their active materials become nearly exhausted and they must be recharged with electricity before thay can be used again. Here lies the difference between the storage battery and the ordinary primary battery. The active materials in the primary battery when once exhausted cannot be brought back to generate electricity, and must be renewed.

The term battery is applied to two or more cells, whether primary or storage types, which are connected together to increase the total amount of electrical energy delivered to a circuit.

Primary Batteries.—A primary cell consists essentially of a vessel containing some acid called the electrolyte in which are immersed two solid conductors of electricity, called electrodes, one of which is more easily attacked by the acid than the other. A simple cell consists of a weak solution of sulphuric acid, as an electrolyte, a plate of zinc, which is easily decomposed by the sulphuric acid, and a plate of some other solid like copper or carbon which resists the action of sulphuric acid. If the plates of zinc and copper are put side by side in a vessel containing sulphuric acid, and the circuit is completed by joining the two plates by a wire, chemical action will be set up within the vessel or cell. The zinc will dissolve in the acid, forming zinc sulphate, hydrogen will be given up by the sulphuric acid in streams of bubbles which will settle on the copper plate, and a current of electricity will be generated. The bubbles of hydrogen liberated from the electrolyte do not combine with the copper plate, but form a gaseous non-conducting film over the metallic surface which increases the resistance of the cell to the flow of electric current. The formation of the bubbles of hydrogen on the copper plate, called polarization, causes a rapid falling off in the power. It is possible to decrease or even eliminate polariza-

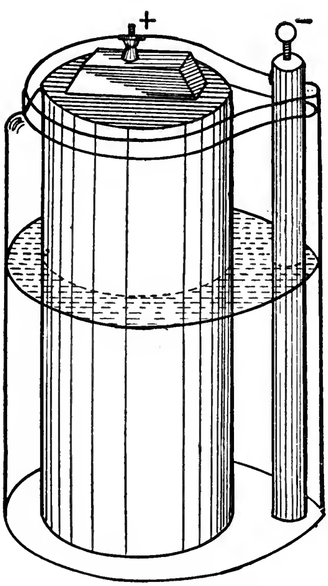


Fig. 209.

tion. One good method is to construct the cell with some strong oxidizing agent. The oxidizing agent gives up its oxygen,

Fig. 210.

which combines with the particles of hydrogen, forming water and decreasing polarization. Cells using this method of decreasing polarization usually employ carbon plates, as most of the oxidizing materials attack copper plates. The Leclanche cell shown in Fig. 209 is an example of this type of cell.

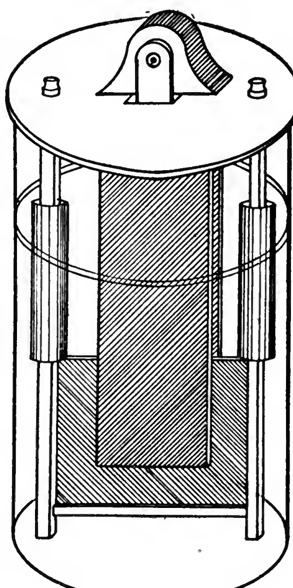


Fig. 211.

The dry cell, which is used extensively at the present time on account of its portability, is a modification of the Leclanche cell. It has zinc for the positive electrode, carbon for the negative electrode, sal-ammoniac and zinc chloride as the electrolyte for decomposing the zinc, and some oxidizing agent like manganese dioxide to eliminate polarization. As usually constructed the dry cell consists of a zinc cylinder which is the positive electrode and acts at the same time as a container for the other materials of the cell. The zinc cylinder is provided with a lining composed of plaster of Paris, flour, blotting-paper, or some other absorbent materials saturated with salammoniac and zinc chloride. At the center of the cell is a carbon rod, and this is surrounded by a paste consisting of manganese dioxide and chloride of zinc. The top of the cell is covered with a layer of hard pitch. A small hole through the pitch permits the escape of any gases which may be formed within the cell. The outside of the cell is usually insulated with paper. Several forms of dry cells are illustrated in Fig. 210. The solution in the dry cell evaporates slowly, so that a battery of dry cells will become worthless after a certain time even if it is not used. Generally a dry cell in good condition will have a current strength of 15 to 25 amperes and should show a pressure of 1 1/4 to 1 1/2 volts. A binding post is attached to the carbon and another one to the edge of the zinc cylinder.

The various Lalande wet cells are very good for gas-engine ignition. One form, the Edison Lalande, is illustrated in Fig. 211. One electrode in this cell is of zinc and the other of copper oxide. The electrolyte consists of caustic potash. The oxygen of the copper oxide prevents polarization. A film of heavy paraffin oil is put on top of the electrolyte, so as to prevent the absorption of carbon dioxide from the air by the caustic potash.

Storage Batteries.—The storage cell consists of two plates or electrodes placed in an electrolyte, but as was pointed out in an earlier part of this chapter, this type of cell will give out no current to the external circuit until it is charged with electricity. The storage cell does not store electricity, but energy in the form of chemical work. The electric current produces chemical changes in the battery and these changes produce a current in the opposite direction when the circuit is closed.

In storage batteries both the positive and negative electrodes of a cell are of lead perforated plates. The perforations are filled with certain lead compounds (Pb_3O_4 and PbO), which react with the electrolyte of dilute sulphuric acid, forming lead peroxide on the positive plate and a spongy metallic lead on the negative plate.

The storage cell is composed of an odd number of positive plates and of an even number of negative plates, so that each side of each positive plate faces a negative plate. The plates are insulated from each other and from the bottom and are placed in a glass vessel if the battery is to be used for stationary purposes, and in a vessel of hard rubber if the battery is for portable use. Various forms of storage batteries are illustrated in Fig. 212.

A storage battery can be charged from any direct-current circuit, provided the voltage of the charging circuit is greater than that of the storage battery when fully charged. Before a storage battery is connected to the charging circuit its polarity should be carefully determined, and the positive and negative terminals of the battery connected to the positive and negative terminals of the source respectively. One good method

FIG. 212.

of determining the polarity of the wires from the storage battery or source is to immerse them in a glass of salt water. Bubbles of gas will form more rapidly on the surface of the negative wire. Another test is that the negative wire will turn blue litmus paper red. Should the positive wire of the battery be connected to the negative wire of the source, the effect would be a discharge of the battery, and this being assisted by the incoming current, a reversal of action would take place, which is very injurious to the battery. It is not well to charge a battery at too rapid a rate, as this will raise its temperature and will cause buckling of the battery plates. It is also well to charge batteries at regular intervals. A storage battery when fully charged will show 2.2 to 2.5 volts on open circuit and about 2.15 volts when the circuit is closed. A storage battery should never be allowed to run down to a voltage lower than 1.8.

Storage batteries are rated by their ampere-hour capacity, this rating being based on the time required for the storage battery to discharge. Most manufacturers of storage batteries specify the rate of discharge. If the rate of discharge is greater than the specified amount, the capacity of the battery is reduced. A battery having a capacity of 800 ampere hours, means that the battery is capable of furnishing 100 amperes for 8 hours. If the battery is connected to a circuit requiring 200 amperes, the capacity will be reduced. In connection with this it should be understood that a single storage battery cell is only capable of furnishing a pressure of about 2 volts. If a storage battery is to supply 110 volts, about sixty cells will be required.

The positive and negative plates of a storage battery can be distinguished by their color. The positive plates when fully charged should have a dark chocolate color, and the negative plates more of a metallic lead color.

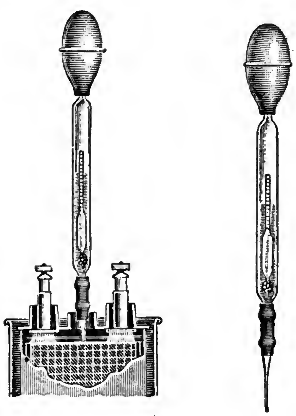


Fig. 213.

For successful operation and long life, storage batteries should be tested frequently with a pocket voltmeter for voltage and with a hydrometer for the specific gravity of the electrolyte. A battery hydrometer for obtaining the specific gravity is illustrated in Fig. 213. The specific gravity of the electrolyte should vary from 1.17 to 1.22 when the battery is in good condition. If too low, add stronger sulphuric acid until the correct specific gravity is obtained.

For gas-engine ignition the storage battery is preferable to the primary dry or wet battery on account of its greater capacity and more uniform voltage. It is, however, more expensive and can only be used in places where direct current is available for recharging purposes.

Storage batteries are used to a considerable extent, as will be explained later, for farm lighting to shorten the running hours of the engine and dynamo, and also in connection with the axle system of train lighting. In large electric power plants, the storage battery finds application during the hours of heavy load.

Methods of Connecting Batteries.—The various methods of connecting batteries are illustrated in Fig. 214 to 216.

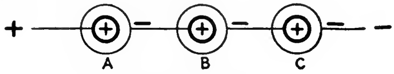


FIG. 214.

In the series battery connection (Fig. 214) the positive (+) of one cell is connected to the negative (−) of the other cell. The voltage of the battery is equal to the sum of the voltage of the cells A, B and C, while the current is equal to that of one cell only. If three storage cells, each having a pressure of 2.1 volts are connected in series, the pressure of the battery is 6.3 volts.

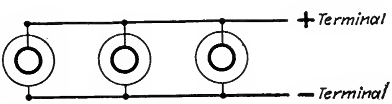


FIG. 215.

The multiple battery connection method is illustrated in Fig. 215. In this case the positive terminals are connected, as are also all the negative terminals of the battery. If the external resistance is low, the current of the battery is proportional to the number of cells, while the pressure in volts is equal to that of one cell only.

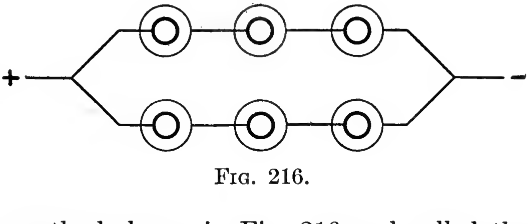


FIG. 216.

Another method shown in Fig. 216 and called the multiple-series method of connecting batteries consists of connecting the battery in two sets, the cells of each set being connected in series and the two sets are connected in multiple. The effect of this method of connecting cells is that the total pressure of the system is equal to that of three cells and the current is equal to that of two cells.

The Electric Dynamo.—The electric dynamo or generator consists essentially of an armature composed of coils of wire wound around an iron core, and one or more magnets. Either the armature or the magnets must be given motion by some form of motor with relation to the other before the dynamo can generate a current of electricity.

The magnet may be a permanent magnet or an electromagnet. A permanent magnet is made of hard-tempered steel which after having been brought under the influence of some magnetizing apparatus, will retain a certain amount of magnetism. Permanent magnets are expensive to make in large sizes and do not hold their magnetism for any length of time. They are employed only in the construction of small electric dynamos, called magnetos, which are used mainly in connection with electric ignition systems for gas engines, and for signaling work.

Dynamos which generate electric current for commercial purposes employ electromagnets. An electromagnet consists of a piece of iron which has wound around it many turns of insulated copper wire. If a current of electricity is passed through the insulated copper wire, the iron becomes immediately magnetized, and remains magnetized as long as the current is passing through the wire. There is practically no limit to the strength of an electromagnet, as this depends only on the number of turns of copper wire and on the current passing through the wire, or on the ampere turns.

Action of the Dynamo.—The action of a dynamo depends on the fact that when a wire or other conductor of electricity is moved between the poles of a magnet, electrical pressure is induced in the conductor. In the simple dynamo, an armature consisting of only one coil of wire is rotated between the north and south poles of a magnet. The ends of the coil are connected to two insulated rings mounted on a shaft which gives rotary motion to the coil. If two brushes are allowed to bear on the two rings and are connected to a measuring instrument, it will be noticed that the current will flow in one direction during half of a revolution and in the other direction during the next half of a revolution. If the readings of the instrument are recorded graphically a curve like Fig. 217 will be obtained. In this curve the horizontal distances represent the angles turned, while in the vertical distances are recorded values of electrical pressure in

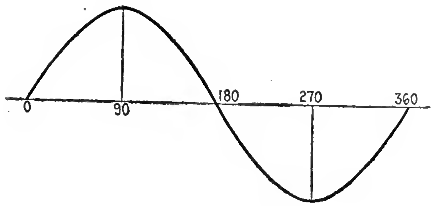


FIG. 217.

volts which cause a corresponding flow of electric current at the various angular positions. It will be noticed that the current starts at zero, and increases to a maximum during one-quarter turn. At the half turn it is zero again. After half of a revolution the direction of the current reverses, attains a negative maximum at three-quarters of a turn and then is again diminished to zero.

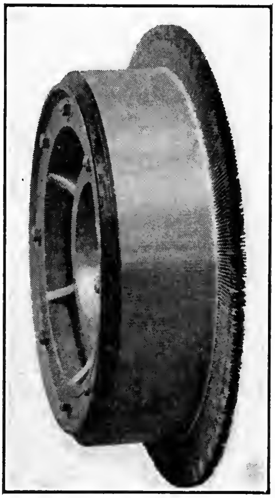


FIG. 218.

Direct and Alternating Currents.—The action of the simple dynamo, explained in the last section, produces an alternating current, which varies from a maximum to a minimum, first in one direction and then in the other. In the actual dynamo there are many conductors in the armature and several sets of poles, so that as the armature revolves, the current reverses its direction many times a second. For long-distance electric transmission this type of electric current is usually used, as alternating currents can be generated at very high voltage, and these voltages can be increased or decreased at pleasure by means of simple instruments called transformers. There are, however, certain uses to which the alternating form of electric current cannot be put. One case was mentioned in connection with the charging of storage batteries, where a direct current must be used, the chemical action as is necessary in a storage battery being an impossibility with an alternating current.

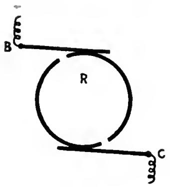


Fig. 219.

Direct current is generated in a dynamo by the addition of a commutator shown in Fig. 218, which consists of a set of segments insulated from each other and from the armature shaft, and which rectify the current by shifting the position of the brushes with respect to the armature coils. The principle of the commutator can be seen from Fig. 219. R is a split ring to the two segments of which are fastened the two ends of the coil, explained in connection with the working of the simple dynamo. The two brushes BC are connected to two wires carrying off the current to the external circuit. As the coil of the simple armature gets into the vertical position between the poles of the magnet each brush changes from the segment with which it was in contact to the other, so that the effect is just the same as if the brushes were interchanged, and the current generated during the second half of the revolution flows in the same direction round the external circuit as the preceding current did. The current although generated in the reverse direction enters the external circuit at the other end, and the result is a unidirectional current. This is changed into a direct current by the employment of an armature with a large number of coils and a commutator of many segments.

Principal Parts of Dynamos and Motors.—The principal parts of all dynamo—electric machinery, whether they be generators of electricity or motors driven by electric current, are:

1. A magnetic field, commonly called a field, whose function it is to furnish magnetic lines. In the earlier machines this consisted of a two-pole magnet but the modern dynamos and motors are provided with four or more poles. The reason for this is that a more compact machine can be produced. A dynamo whose field consists of a two-pole magnet is called a bi-polar, while one with a magnet consisting of four or more poles is called a multipolar dynamo.

2. An armature which is made up of insulated windings of copper wire on an iron core. The function of the armature is to cut the magnetic lines of force furnished by the field. In all direct-current machines the field is the stationary part while the armature revolves. In alternating-current machines, the field is the revolving part in all but the very small machines.

3. A device which collects or delivers current to the armature, depending on whether the machine is a generator or a motor. In the case of alternating-current dynamos and motors this is accomplished by brushes pressing on collector rings, if the arma-

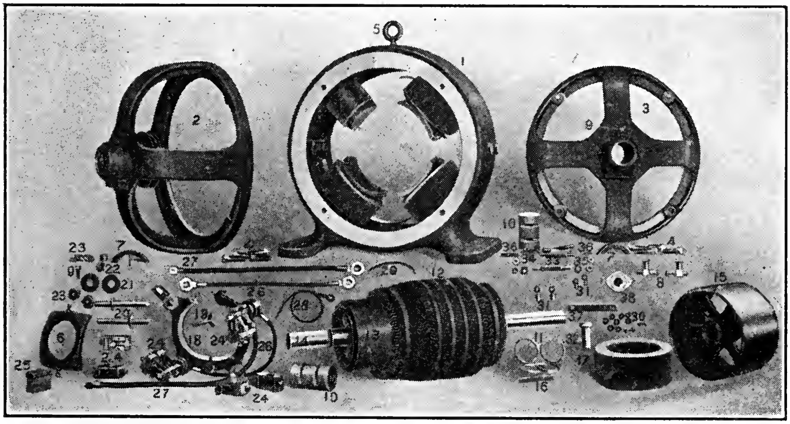


Fig. 220.

ture is the revolving element. In larger alternating-current machines where the armature is the stationary part, the current is taken away from or delivered to the windings by leads entering the frame of the dynamo or motor. When dealing with direct-current machines, current is delivered to or taken away from the armature by brushes pressing on a commutator whose function, as explained in the earlier part of this chapter, is also to change the alternating current into direct current.

4. A shaft passing through the revolving part, which is connected to the engine furnishing power in the case of the dynamo and to the machine to be driven in the case of the electric motor.

5. A frame, usually made of cast iron, whose function it is

to support the bearings in which the shaft of the dynamo or motor revolves.

The various parts of a direct-current generator or motor

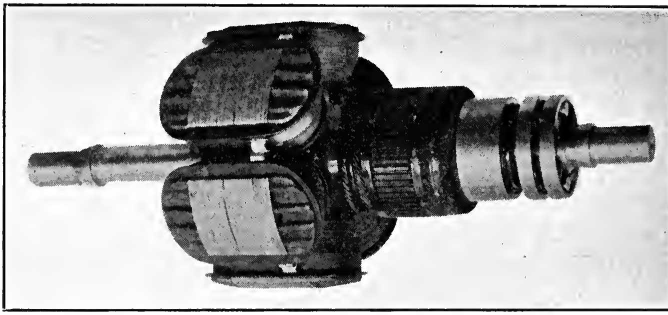


FIG. 221.

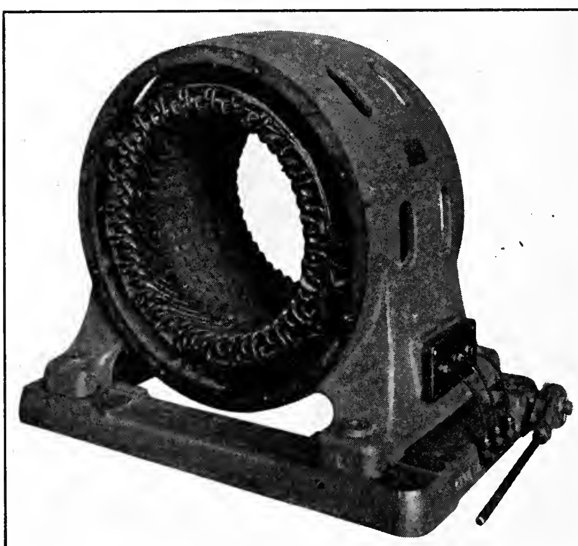


FIG. 222.

are illustrated in Fig. 220. The field and armature of an alternating-current generator are illustrated in Figs. 221 and 222 respectively.

Classification of Dynamos and Motors.—The first broad classification is into direct and alternating-current dynamos and motors.

Direct-current dynamos and motors are divided into three classes depending on the type of field winding as series wound, shunt wound, and compound wound. For simplicity these three types are represented as bi-polar machines in Figs. 223, 224, and 225.

Series-wound Dynamos.—In the series-wound dynamo, illustrated by Fig. 223, one end of the field winding is connected to the positive brush and the other to the external circuit. The

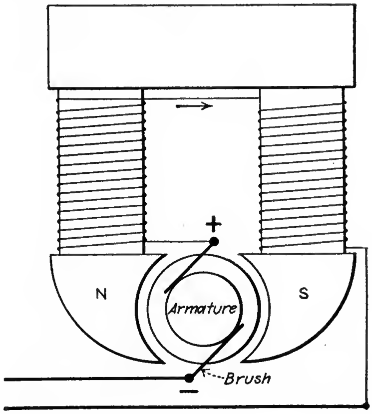


FIG. 223.

action of the series-wound machines depends on the fact that the soft iron poles retain sufficient mangetism to send out a current to the external circuit when the armature is rotated. The entire current passing through the field, the electromagnet of the field increases in strength as the current developed by the generator becomes greater. Series-wound dynamos are used mainly to supply electricity to direct-current arc lamps.

Series-wound Motors.—The series-wound motor has a winding similar to that of the series-wound dynamo. In fact it is impossible to tell the difference between any direct-current motor and dynamo, the electrical features being the same. A series-wound dynamo when operated as a motor will run in reverse direction. The series-wound motor is used for work where hand control can be used as in the operation of hoists, cranes, and for the propulsion of electric cars. A series-wound motor can be started at full load and should never be used where there is a possibility for the load to be removed suddenly. A series-wound motor will "run away," that is its speed will increase to such an extent that it may be destroyed by centrifugal force, if the load is removed. For this reason it is not safe to use belt drives with series-wound motors. A series motor is illustrated in Fig. 223.

Shunt-wound Dynamos.—The principle of a shunt-wound dynamo is illustrated in Fig. 224. The field winding consists of a

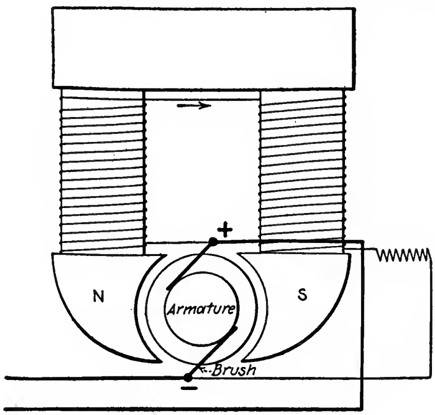


Fig. 224.

great number of turns of very fine wire. Both ends of the field winding are connected to the brushes of the dynamo. Since the field winding is very small in comparison to the line wire, only a small part of the current flows around the field coils. This type of dynamo is used for charging storage batteries. A shunt-wound dynamo will supply constant voltage provided the load does not vary much.

Shunt-wound Motors.—The shunt-wound motor has the same type of winding as the shunt-wound dynamo. Shunt-wound motors are used for all kinds of work where fairly constant speed is desired. A well-designed shunt-wound motor will not vary much in speed with a variable load. In starting a shunt-wound motor it is necessary to put a considerable resistance in series with the field of the motor. This is due to the fact that the resistance of the armature of shunt-wound motor is very low. If a voltage of 110 to 220 volts is allowed to pass through an armature of low resistance, an enormous current would flow through the armature in starting, which would result in injury to the armature coils, and also to the commutator by excessive sparking. By putting a resistance in series with the armature the current which is allowed to pass through it is decreased. Then, as the motor begins to speed up, the armature turning between poles of a magnet, produces a dynamo action which sends an electrical pressure in opposition to that which is sent in from the mains. This tends to reduce the current passing through the armature to a

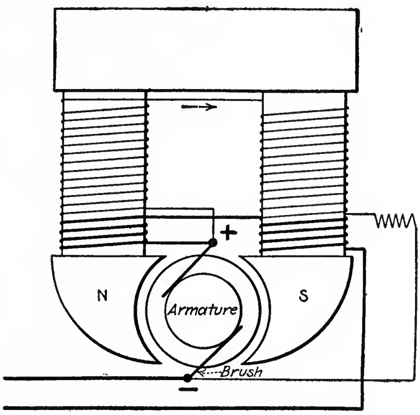


Fig. 225.

safe limit. In connection with this, it must be remembered, that weakening the field of a shunt-wound motor, reduces the above-mentioned dynamo action, and speeds up the motor. A break in the field connection of a shunt-wound motor, while it is in operation, may result in considerable damage by overspeeding.

Compound-wound Dynamos.—The compound-wound dynamo is used extensively for the generation of current for all purposes, including that for light, power and street-car propulsion. The voltage of this type of machine is automatically regulated by a combination of a shunt and series winding. This type of winding is illustrated in Fig. 225. A large portion of the field is wound with many turns of fine insulated wire, which must produce a field of sufficient strength to generate the rated voltage of the dynamo when no load is placed on it. A series winding of several turns of heavy wire is wound over the shunt winding. This series winding adds sufficient strength to the field so as to develop the standard voltage at the maximum load of the dynamo. In some compound-wound dynamos, the series winding is arranged to increase the voltage slightly as the load increases, and to compensate for loss in voltage during transmission.

Compound-wound Motors.—The compound-wound motor has a series and shunt winding like the compound-wound dynamo. It is used mainly for the driving of machines where very close speed regulation is essential, such as printing presses, machine tools, and looms.

Various Types of Motors Compared.—For most purposes, the shunt-wound motor is very satisfactory, and, being much cheaper than the compound-wound motor it is used for the driving of all kinds of machinery, which can be started at no load. If motors are to be used for pumping the series-wound or compound-wound motor should be selected, unless a clutch can be inserted between the motor and pump.

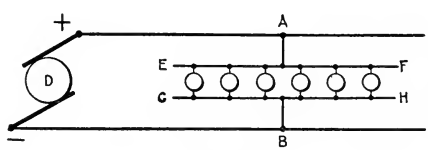


Fig. 226.

Distribution of Electric Current.—Electricity may be distributed as direct or as alternating current. Direct current is usually used for short-distance distribution, the most common voltages being 110 and 220 volts. If the furthest point of the distributing system is a mile or further from the dynamo it is well to use alternating currents in order to reduce the cost of wire. Alternating currents are used in voltages of 1100, 2200, 4400, 6600, and higher.

When using direct currents the parallel system of distribution is most common. The principle of this system is illustrated in Fig. 226. The feeders A and B lead from the dynamo D to the switchboard. The mains EF and GH connect the feeders with the branches which supply current for lamps, motors, etc.

In another system of direct-current distribution, the series, shown in Fig. 227, the lamps are connected in series with the dynamo D. This system is very seldom used at the present time, and then only for supplying current to direct-current street arc lamps.

Electric Meters.—The four most important quantities which must be known are: current, voltage or electrical pressure, resistance and power. Then most switchboards are also provided with ground detectors for the purpose of telling when the circuit is grounded.

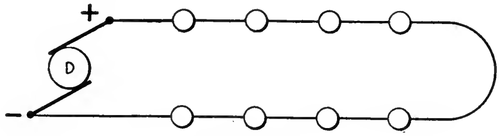


Fig. 227.

Electric current is measured by an instrument called an ammeter, and illustrated by Fig. 228. This instrument usually con-

Fig. 228.

Fig. 229.

sists of a coil of wire between the poles of a permanent magnet. The current to be measured is sent through the coil, this producing a movement of the coil which is recorded by a needle on a graduated scale.

A voltmeter, illustrated in Fig. 229 is used for measuring electric pressure. This instrument differs from the ammeter in that a resistance is placed in series with the coil, otherwise the voltmeter and ammeter for the measurement of direct current are alike.

For the measurement of voltage and current of batteries a battery meter illustrated in Fig. 230 is used.

The method of connecting an ammeter M and a voltmeter V to a circuit is shown in Fig. 231. AB and CD are the two wires of the circuit.

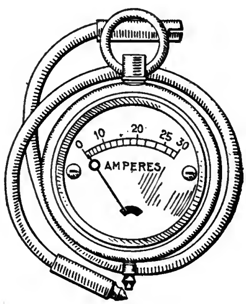


Fig. 230.

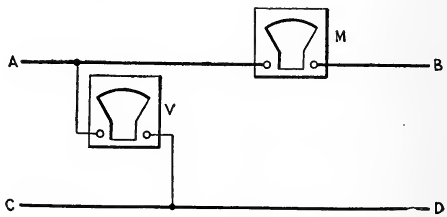


Fig. 231.

Resistance can be measured by using a voltmeter and an ammeter together. The ammeter is connected in series with the resistance, while the voltmeter is connected to the terminals. The resistance can then be calculated by Ohm's law, explained in the beginning of this chapter. If I is the ammeter reading and E is the voltmeter reading the resistance is:

$$R = \frac{E}{I}$$

An instrument which measures the electrical power of a circuit is called a wattmeter. Since the power of a direct-current circuit is the product of the current flowing through the circuit by the voltage between the terminals, the power can be obtained by taking the product of the voltmeter and ammeter readings of any circuit. In alternating-current circuits this product of the voltmeter and ammeter readings does not give the true electric power of the circuit and a wattmeter must be used. Direct and alternating current wattmeters are illustrated in Figs. 232 and 233 respectively.

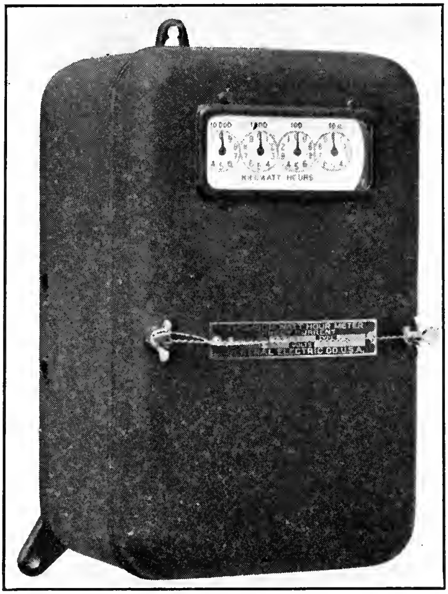


Fig. 232.

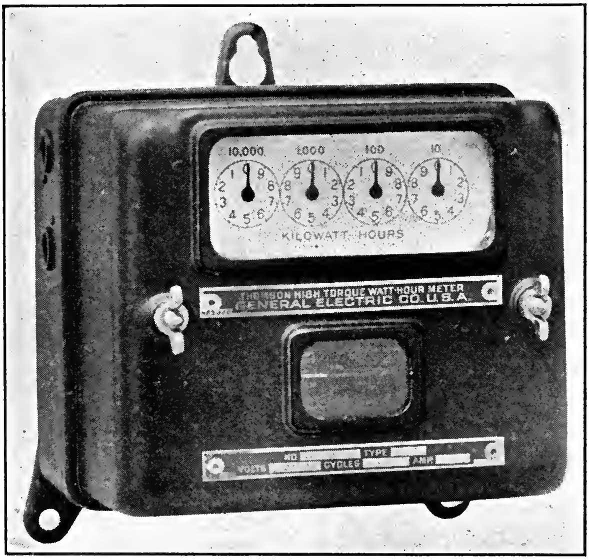


Fig. 233.

A ground detector can usually be made by connecting two lamps as shown in Fig. 234. The two lamps LL′ are connected to the two terminals and the junction between the two lamps is

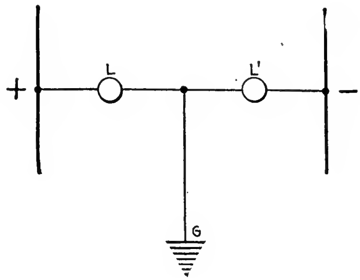


FIG. 234.

grounded to a water pipe. When the system is free from grounds both lamps will burn dim, but when a ground occurs on either line the opposite lamp will burn bright.

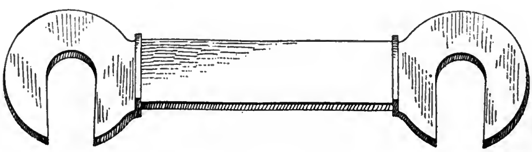


FIG. 235.

Fuses and Circuit Breakers.—The function of fuses and of circuit breakers is to protect electric machines, appliances and wires from being traversed by currents above their safe carrying capacities.

FIG. 236.—Edison plug cut-out and fuse.

Fuses are made of an alloy of lead and zinc. For temporary connections fuse wire is used. A better method is to solder the wire to copper terminals as shown in Fig. 235. The Edison plug cut-out and fuse, illustrated in Fig. 236 is very convenient. Another form, the enclosed type of fuse, is shown in Fig. 237.

Due to the uncertainty and unreliability of fuses, circuit breakers are employed for the protection of lines carrying heavy currents.

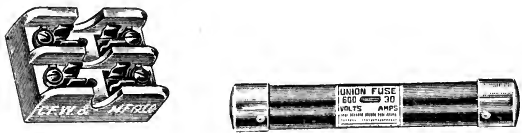


Fig. 237.

Several forms of circuit breakers are illustrated in Fig. 238. A circuit breaker is a switch which opens automatically where the current passing through it is greater than that for which it is set. Circuit breakers are made to open either one or both sides

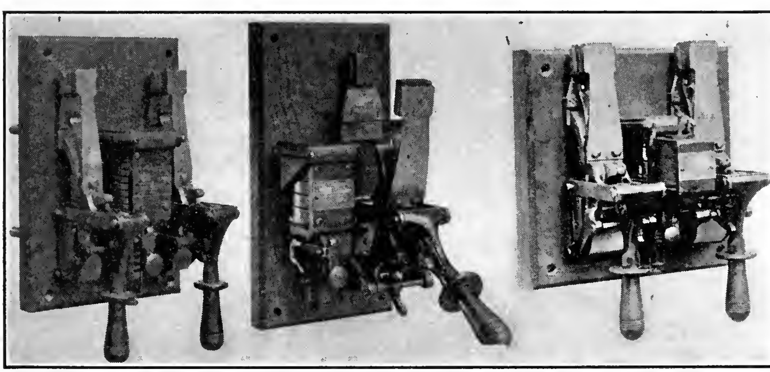


Fig. 238.

of the circuit and are named accordingly single-pole and double-pole circuit breakers respectively.

Switches and Rheostats.—The functions of a switch and rheostat in an electrical circuit are analogous to that of a valve in a steam or water line. The switch opens or closes the circuit while the rheostat regulates the strength of the current passing.

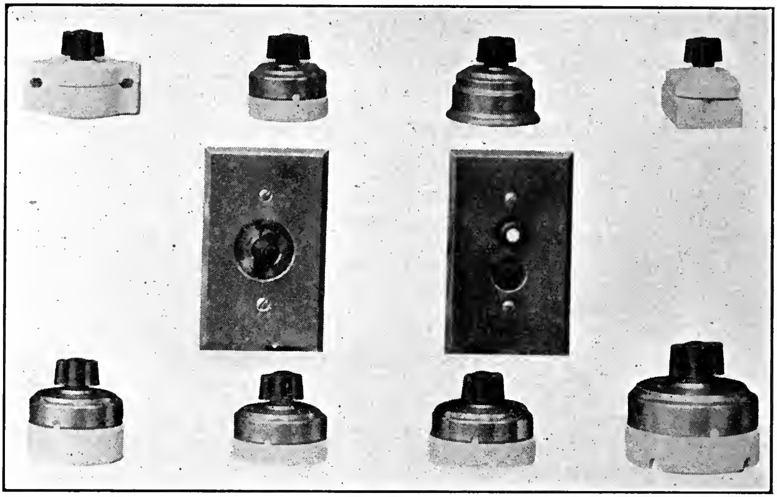


Fig. 239.

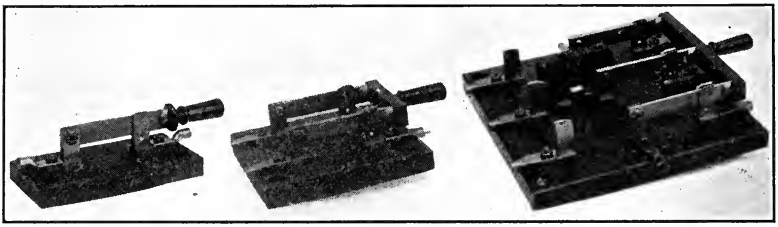


Fig. 240.

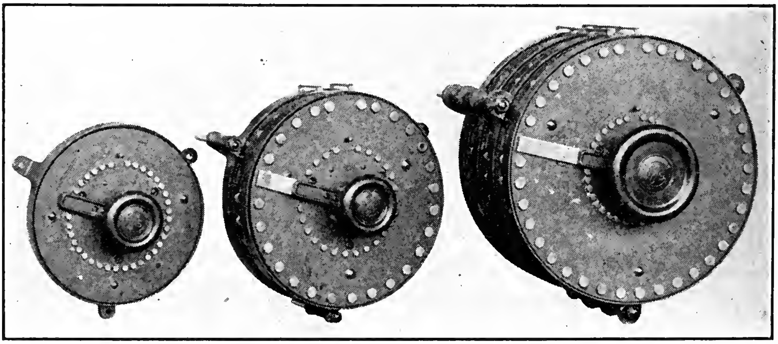


Fig. 241.

For controlling the flow of small currents in connection with the illumination of rooms, some form of snap switch or push-button switch is employed. These switches can be brought to control the current from two, three or four different places. A special form of push-button or snap switch, called the electrolier

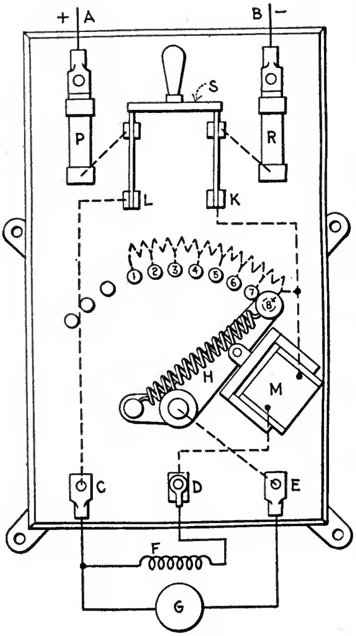


FIG. 242.

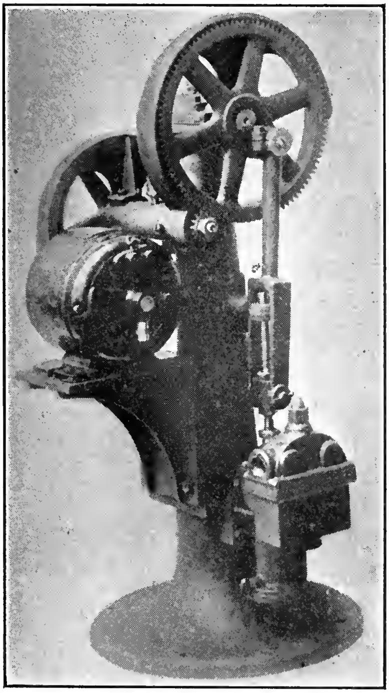


FIG. 243.

switch can be used for turning on part of the lamps on an electric-light chandelier. Thus in the case of a 4-light chandelier, this type of switch can be wired so that the burning of one, two, three or all of the lamps can be controlled from the wall of the room. Several forms of snap and push-button switches are illustrated in Fig. 239.

For currents above 25 amperes a knife switch should be employed. This type of switch has a contact-making piece of a shape somewhat like a knife. A single-pole knife switch opens only one side of a circuit, a double-pole two sides, etc. Double-throw switches are used when one of two circuits has to be controlled at a time. Several forms of knife switches are illustrated in Fig. 240.

A rheostat for controlling the strength of electric current is illustrated in Fig. 241. The fundamental parts of a rheostat are: coils of iron wire to absorb electric current, metallic points connecting the various coils to the outside, and an arm which is moved over the various points.

Method of Connecting Motors.—The method of connecting a shunt motor and its starting box to the circuit is illustrated in Fig. 242. A and B are the two leads which bring the current from the mains (connected to a dynamo) through the fuses P. R. and to the switch S. One terminal of the switch L is connected to the field F and to the armature G of the motor. The other terminal K leads to the starting box. The handle H of the starting box is connected with the terminal E, which is attached to the armature of the motor. The other terminal D of the starting box is connected with the field of the motor F.

When the motor is to be started, the switch S is closed and the handle H is on the contact point 1. The handle H is then moved slowly to the right. When the handle H is on the last contact point, it is held in position by the magnet M. To stop the motor, the switch S is opened. The magnet M, losing its magnetism allows a spring to bring back the arm H to the starting-point.

The Electric Motor on the Farm.—The electric motor is well suited for most farm work which is accomplished by the small stationary gasoline engine. It is not as portable in any but the very small sizes, but possesses other advantages for certain uses. A small electric motor requires no special foundation and may be placed on the floor, on a truck, or may be fastened to the wall or ceiling, is easily started and requires less care than the gasoline engine. The cleanliness of the electric motor and the absence of offensive fumes makes it more desirable for use in the house, the dairy and the barn.

The use of the electric motor in the home is illustrated in Figs. 243 to 248. The house pump driven by a motor of $\frac{1}{6}$ h.p. is shown in Fig. 243. Another electric motor of $\frac{1}{10}$ h.p. drives a washing machine illustrated in Fig. 244. Still a smaller motor is shown connected to a sewing machine in Fig. 245. Other uses to which the electric motor can be put in the farm household may be mentioned: the driving of fans during hot weather

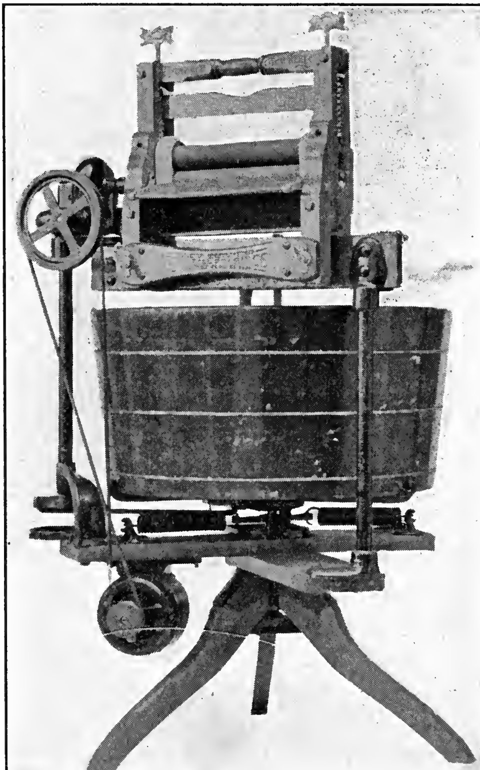


Fig. 244.

(Fig. 246), of vacuum cleaners, of ice-cream freezers, of cream separators (Fig. 247), churns, of milking machines and of grindstones (Fig. 248). An electric motor can also be used for the shelling and grinding of feed and for the many operations in the farm shop.

For out-door use and for the heavier farming operations the electric motor is not as suitable as the gasoline engine.

The application of electric motors to grain elevators, chop mills and flour mills are illustrated in Figs. 249 to 251.

The Farm Electric-light Plant.—For farms of the average size, which do not have the advantages of cheap power from

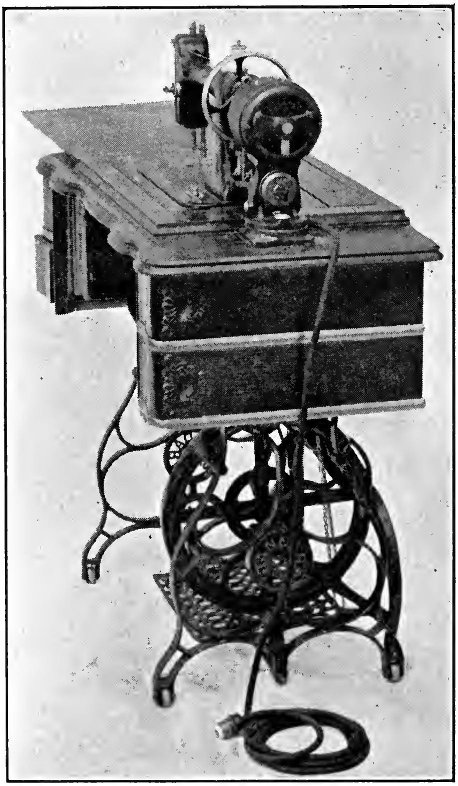


Fig. 245.

a nearby transmission system, private electric-lighting plants driven by gasoline engines are becoming quite common.

When an electric-light plant is to supply current for lighting only, the complete installation including the wiring of an average eight-room house and barn will vary from $500 to $750. If the

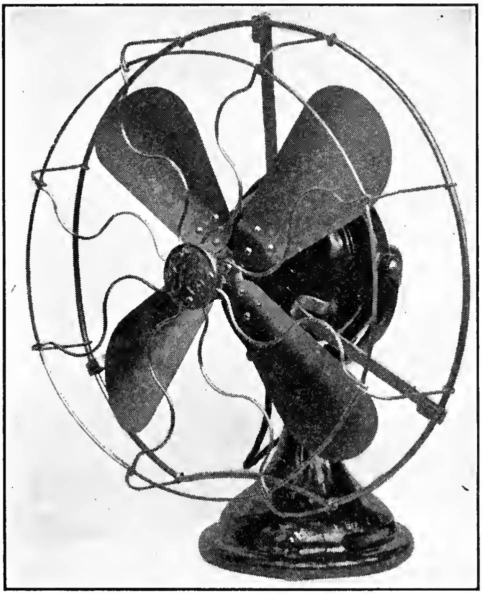


FIG. 246.

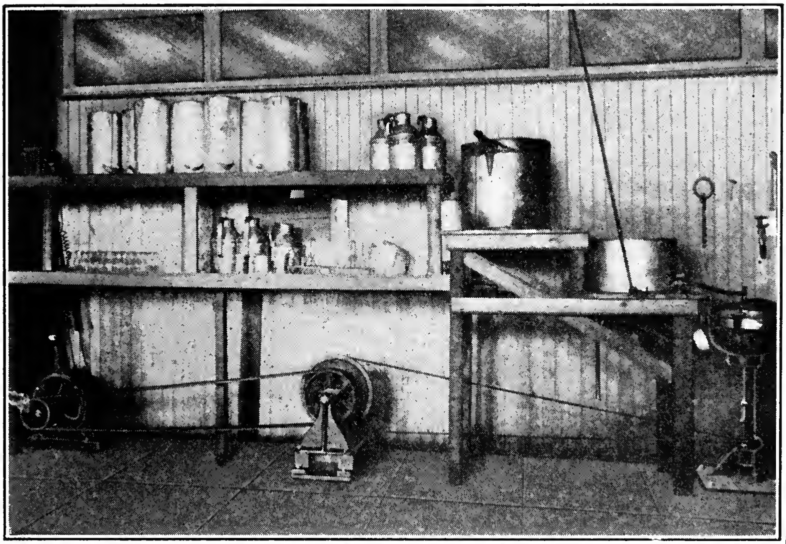


FIG. 247.

Fig. 248.

Fig. 249.

plant is to supply current for motors as well as for lights the first cost will be from $1200 up, depending on the size of motors used. The cost of operating a plant for lighting only will usually be about $15 a year. The cost of operating plants which supply electricity for power will depend on the size of motors and on the amount of work done.

The essential parts of a private electric-light plant are:

1. A gasoline engine and a dynamo.

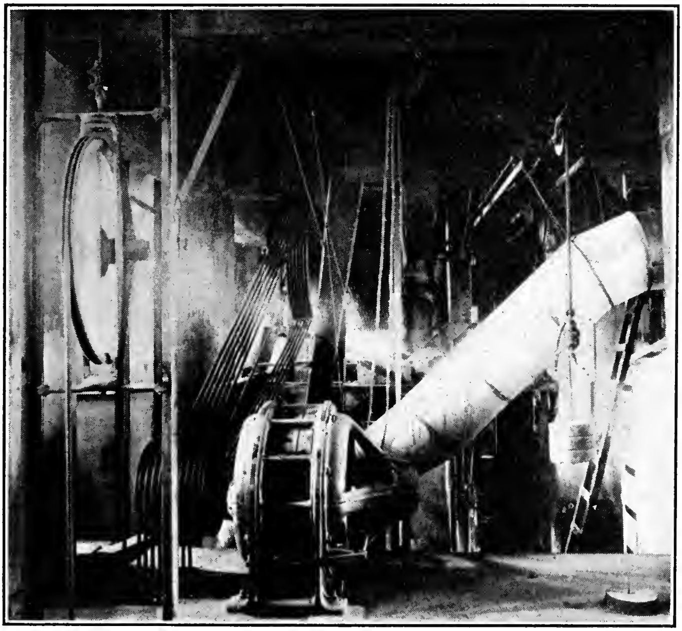


Fig. 250.

2. A set of storage batteries for storing the electricity to be used when wanted and which supplies a steady light whether the engine is running or not.

3. A switchboard with an ammeter, voltmeter, fuses and switches to control operation of the dynamo and of the storage battery.

4. Wires from the switchboard to the house, barn and other places where electricity is to be used.

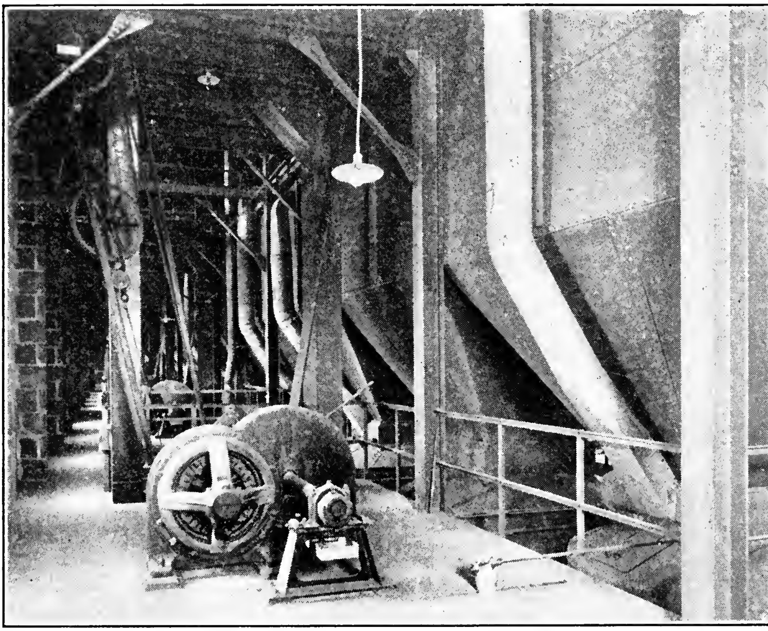


Fig. 251.

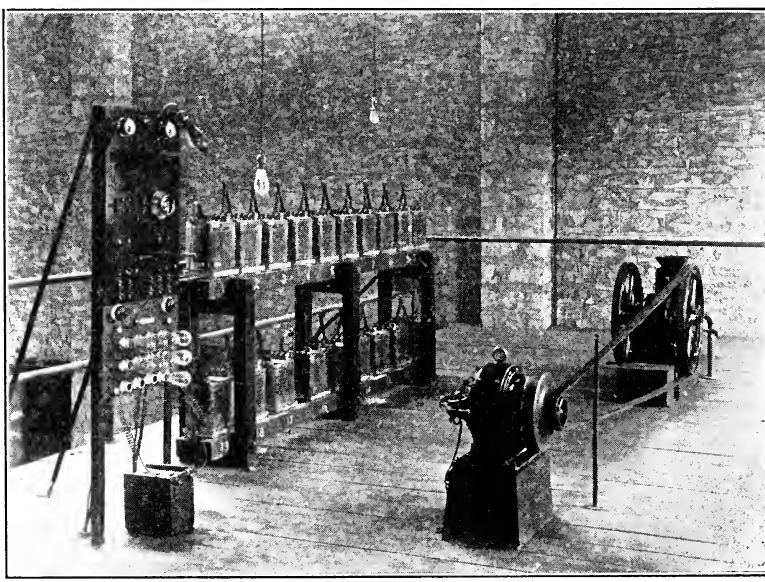


Fig. 252.

5. Wiring of the house, barn, etc.

In Fig. 252 is illustrated a farm electric-light plant, which was installed in the engineering laboratories of the Kansas State Agricultural College for experimental purposes.

The use of the private electric-light plant for farms of average size was out of the question until quite recently on account of the great cost of the storage battery. With the ordinary carbon lamps operating at 110 volts, about sixty storage cells were required to maintain the correct voltage when the engine was not running.

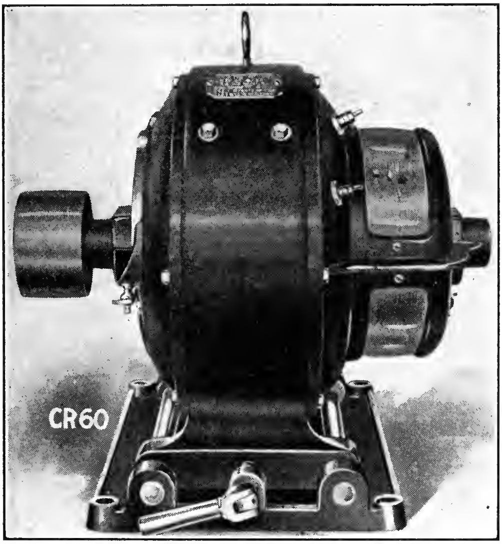


Fig. 253.

The development of the tungsten lamp, which operates satisfactory at about 30 volts, necessitates the use of a battery of only seventeen cells, and has the added advantage of greater safety from short circuits. Then the tungsten lamp consumes only about one-third of the electric energy required by the carbon lamp of the same candle-power.

Installation of Electric Motors and Dynamos.—A dry, cool and clean place, free from dust, should be chosen for the location of an electric machine. If the surrounding air is warm, the temperatures of the various parts is likely to rise to a sufficient degree as to endanger armature, or field, or both.

If a motor has to be located in a dusty place, or in connection with farming operations where particles of feed or trash may lodge on the motor, an enclosed type like the one shown in Fig. 253 should be selected.

In locating motors or dynamos care should be taken to provide easy access to all parts. Also sufficient distance must be allowed between the pulley centers of the driver and driven.

A substantial foundation of timber, brick or concrete should be provided for all motors and dynamos above 25 h.p. Small machines can be fastened to the floor and require no special foundation.

If an electric machine has been exposed to changes of climate, it should be kept in a warm dry place for several days, as the insulation always absorbs dampness which can be only slowly dried out.

Small machines are usually shipped complete and ready to run. Large motors and dynamos are usually shipped in boxes, "knocked down," as this reduces freight charges.

In assembling parts, all connections and parts should be wiped perfectly clean and free from grit. The bearing sleeves and oil rings should be placed in position on the shaft before the armature is lowered in place.

The bearings should be filled with a good grade of thin lubricating oil, care being taken not to fill the oil cellars so they will overflow.

In clamping the brushes in place, they should be adjusted so that the pressure on the commutator is about 1 1/2 lb.

The brushes are fitted to the commutator by passing beneath them No. 0 sandpaper, the rough side against the brush and the smooth side held down closely against the surface of the commutator. The sandpaper should be moved in the direction of rotation of the armature, and on drawing it back for the next cut, the brush should be raised so as to free it from the sandpaper. It is then lowered and repeated until a perfect fit is obtained between the brush and commutator.

Starting and Stopping Motors.—Before starting a machine for the first time, care must be taken that all set screws and nuts are tight and that the oiling system works properly. The armature is then turned by hand to see that it is free and does not rub or bind at any point. The wiring should be carefully gone over and all terminals screwed down tightly. When everything is in good condition, the switch is closed, but before doing this one must make certain that the starting-box handle is in the "off" position. After the switch is closed, the handle on the rheostat is moved, gradually cutting out the resistance as the motor speeds up.

It is well to run a new motor for a time before putting on the load.

In stopping a motor, pull the switch and the handle of the starting rheostat should fly back to the "off" position.

Starting and Stopping Dynamos.—The general rules regarding getting an electric machine ready to start are alike for the dynamo and motor. When the dynamo is ready to be started, place the driving belt on the pulley of the armature shaft and start the engine driving the dynamo, bringing the machine up to speed very slowly.

Dynamos are usually tested before they leave the factory. As a rule, dynamos will retain sufficient magnetism in their fields so they can be started. Sometimes a dynamo loses its field magnetism on the way from the factory to its destination. The fields can be magnetized by current from a battery or from another dynamo.

If a dynamo is supplying incandescent lamps, the main switch should not be closed until the machine is developing the correct voltage.

In stopping a dynamo, the load is first removed and the engine driving the dynamo is then stopped in the usual manner.

Care of Motors and Dynamos.—It is very important to keep electric machines clean and all insulation free from dust and gritty substances.

The commutator should be kept clean and allowed to assume a glaze while running. Oil should not be used on commutators, as it chars under the brushes, forming a film between commutator bars which may cause a short circuit.

The commutator brushes should be kept in good shape. They should be removed frequently for inspection and cleaning, and if necessary should be filed. To remove grease or dirt the brushes should be soaked in gasoline.

If the brushes are not properly trimmed or are in poor condition the commutator will present a bright coppery appearance and will be found rough when felt by hand. If in very poor condition, the commutator may have to be turned down.

Sparking at commutators will usually occur if brushes are improperly set, commutator is rough, machine is overloaded, short circuited or grounded.

Heating of armatures may be caused by the short circuiting of some of the armature coils or by too great a load. A short-circuited armature coil can be usually detected by its high temperature. If a greater part of the coils are short circuited the determination becomes more difficult and sensitive instruments have to be used.

A hot bearing will also cause the heating of the armature, and this can be usually detected and remedied.

PROBLEMS

1. How much current would an ordinary 32 candle-power carbon filament lamp consume on a 110-volt circuit?

2. Calculate the horse-power of an engine required to supply twenty 16 candle-power and five 32 candle-power carbon filament lamps. Allow 25 per cent. for losses.

3. What horse-power gasoline engine would be required to drive a 5-kw. generator?

4. If an arc lamp consumes 5 amperes at 110 volts, calculate its resistance.

5. How many arc lamps can be operated by a 5-kw. machine, each arc lamp requiring 3.5 amperes on a 220-volt circuit? Allow 5 per cent. for losses.

6. Using the values in Table 7 calculate a table giving the power consumed by carbon filament lamps of various candle-power.

7. Which sizes of rubber-covered and weatherproof wire should be used to transmit 50 amperes? Neglect transmission losses.

8. How would you connect six dry cells to give greatest voltage? Calculate approximate voltage of battery.

9. How should six storage batteries be connected to give the greatest voltage and as large a current as possible. Calculate approximate voltage and current of battery.

10. When should the multiple system of battery connection be used?

11. The reading of an ammeter connected in series with a coil is 18 amperes. If the voltage between the terminals is 7 volts, calculate resistance of coil.

12. Calculate the current which will flow through a resistance of 440 ohms, the voltage between terminal being 110.

13. How does the ground detector explained in this text work? Explain its theory of operation in detail.

14. Can alternating current be measured by direct current instruments? Give reasons for your answer.

15. Give clear abstract of Bulletin No. 25 of the Iowa Engineering Experiment Station. This bulletin deals with electricity on the farm.

16. Name the various parts of a dynamo or motor which are illustrated and numbered in Fig, 220.

CHAPTER XI

MECHANICAL TRANSMISSION OF POWER

While the transmission of power by electric means is advancing rapidly, it is probable that for some time to come power from one machine to another will be transmitted by mechanical means.

Mechanical transmission of power between different machines may be accomplished by means of:

1. Belts.
2. Chains.
3. Ropes and cables.
4. Friction gearing.
5. Toothed gearing.
6. Shafting.

To the above list should be added cams, eccentrics, connecting rods, cranks and levers as means for transmitting power to the various parts of the same machine.

Belts.—One of the most common methods of transmitting power is by means of leather, rubber, canvas or composition belting. On account of slipping, the transmission of power with belts is not positive as is the case with gears.

The simplest arrangement is to have the belt connect two pulleys, one of which is the driver and the other is the driven. The belt may be open or crossed. In the first case the two pulleys turn in the same direction. Connecting two pulleys with a crossed belt reverses the direction of the driven.

The power transmitted by a belt depends upon the adhesion between the belt and the pulley. For indoor work and under reasonably dry conditions, leather has proven to be the most satisfactory and reliable material for belts. It is, however, the most expensive and its use cannot be recommended for outside work in inclement weather.

Leather Belts.—Leather belts are made up of short strips of oak-tanned leather, each strip varying from 44 to 60 in. in length. Before being tanned for belting purposes the head, neck, belly and tail portions of the hide are trimmed off. The remainder of the hide is divided into three portions from which the different grades of belting are secured. The best grade of belting comes from the center piece of the hide, after a strip is cut off crosswise from the shoulders. The second grade comes from the flanks, and the poorest grade from the shoulders.

Leather belting is made of single thickness, and is designated as single ply, or single belt. Double-ply belting is made by connecting the flesh sides of two thicknesses of leather.

The cost of double belting is just twice that of single belting, but it has been found that it will transmit twice as much power and will last more than twice as long as single belting. Owing to the greater stiffness of double belting it will not conform to the surface of the pulley as readily as a single belt, and its use is limited by the size of the pulley. Double belts are generally not used on pulleys less than 10 in.

Rubber Belts.—These consist of one or more layers of cotton duck alternating with layers of vulcanized rubber. The adhesion of rubber belts is somewhat better than that of leather belts. Rubber belts will also stand heat, cold and moisture better than leather belts. The life of a rubber belt is much shorter than that of a leather belt and the coating of rubber is easily ruined by the application of oil.

Canvas Belts.—Canvas belts are lighter than rubber belts. They are well adapted for saw mills or for farm machinery where the belt is exposed to the weather. Canvas belts stretch and contract with temperature changes and are not durable. Painting improves canvas belts.

Care of Belts.—Leather belts must be kept clean and free from dust, dirt and oil. Dampness will loosen the cement which is used in building up the belt. Some manufacturers have now a process of waterproofing leather belts, but this has not been extensively tried out.

Most preparations called "belt dressing" contain rosin and are injurious to leather. If it is necessary to soften a leather belt, neat's-foot oil, tallow or castor oil should be used.

The hair side of a leather belt should be run next to the pulley, as this is the weaker side, and being smoother than the flesh side the hair side will adhere much better to the pulley.

Rubber belts should run with the seam side out, and not next to the pulley . All animal greases and oils should be kept away from rubber belts. Boiled linseed oil may be applied, but this should be done sparingly.

Belts will hold better when the pulleys are at long distances apart. Two pulleys connected by a belt should be spaced far enough apart so as to allow of a gentle sag to the belt when in motion. This distance will be 10 to 15 ft. for narrow belts and small pulleys. In the case of wide belts working on large pulleys the distance between driver and driven should be at least 20 ft. If too great a distance is used the extra cost of the belt will be wasted and the extra weight of the belt will produce unsteady motion and great friction in the bearings.

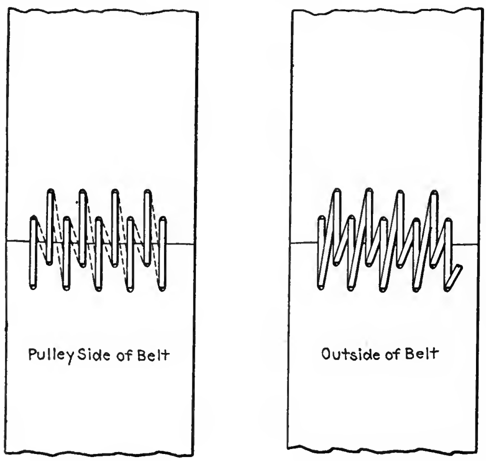


Fig. 254.

Method of Lacing Belts.—The strength of the belt depends not only on the quality of the material from which it is made, but also on the method used in connecting the ends. The ideal joint is a cement joint. Such a joint should be made only after the ends of a belt have been stretched in position over pulleys.

Lacing made of rawhide is most commonly used. Metallic wire lacing will also give good results if the lace wire is hammered below the surface of the leather so as to prevent excessive wear on the lace, and if care is taken not to have two wires cross each other on the pulley side of the belt. Wire lacing makes a less clumsy joint and does not decrease the strength of the belt on account of large holes as does rawhide lacing.

To cement a belt, a lap joint generally equal to the width of the belt is made by beveling the two ends, applying glue and then clamping the two ends together in the required position.

Before a belt is laced the two ends should be made absolutely square, otherwise the belt will tend to run off the pulleys. One method of lacing a belt is illustrated in Fig. 254.

Other methods of connecting the ends of a belt are by means of belt fasteners, rivets, staples and sewing. These methods are not recommended, as they will pull out in time and leave the belt ends ragged.

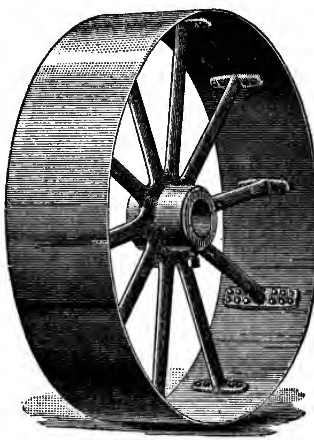


FIG. 255.

Pulleys.—Pulleys are made of iron, wood and paper. Pulleys are either solid (Fig. 255) or split (Fig. 256). Large pulleys are usually of the split type.

Pulleys designed to transmit power by belts are usually crowned, that is the rim is rounded, so that the diameter is greater at the middle. When crowned pulleys are used the belt will remain at the center of the pulley and will not run off. The width of the acting surface or face of a pulley should always be greater than that of the belt.

In order to be able to start and stop the driven pulley without interfering with the driver, a combination of tight and loose pulleys are often used. In this case one pulley is fastened to the shaft and transmits motion, while the other is loose on the shaft. The driving shaft carries a pulley, which has a width equal to that of the tight and loose pulleys put together. The belt when in motion can be shifted so that it will run over the tight or over the loose pulley, thus throwing machinery into or out of gear. Where tight and loose pulleys are employed, or in any case where the belt may be shifted, the pulleys are straight, that is, are built

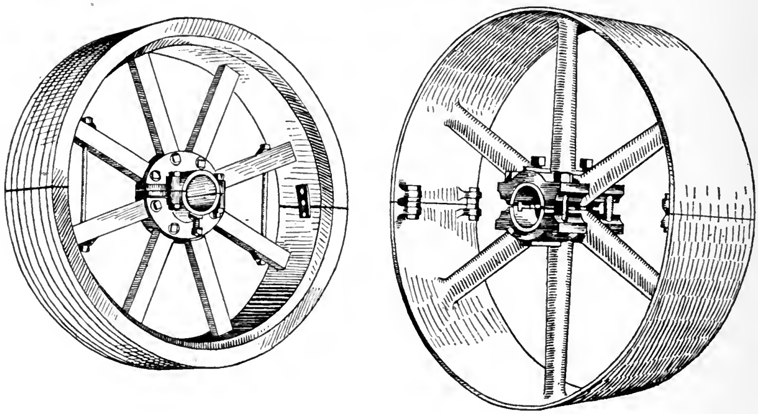


Fig. 256.

without crowning, in order that the belt may be easily moved from one pulley to the other.

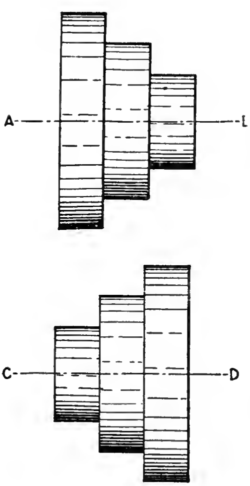


Fig. 257.

The average leather belt will not transmit its maximum force on account of slipping on the pulleys. The adhesion between the belt and pulley can be increased by covering the pulley with leather. This method of increasing the power transmitted should be used only in emergencies. A well-designed drive with the belts and pulleys of proper size to transmit the desired power should not require pulley covering.

Small pulleys are secured to the shaft by means of set screws. Large pulleys are fastened to the shaft by keys, or sometimes by both keys and set screws.

Stepped pulleys (Fig. 257) have several faces of different diameters on both the drivers "AB" and driven "CD," for varying the speed of a shaft by means of a shifting belt.

Method of Calculating Sizes of Pulleys.—If there is no slip in the belt, the speeds of two pulleys connected by a belt will vary inversely as the diameters of the pulleys.

Calling D the diameter of the driver, d the diameter of the driven, N the revolutions of the driver, and n the revolutions of the driven, the following equation holds

$$DN = dn$$

(The product of the diameter of the driver and its revolutions must be equal to the product of the diameter of the driven and its revolutions).

As an illustration: A gasoline engine running at 300 revolutions per minute has a belt pulley 20 in. in diameter. Calculate the size of the driven pulley if it is to run at 600 revolutions per minute.

From the above equation

$$d = \frac{20 \times 300}{600} = 10 \text{ in.}$$

The above rule applies equally well to gears, only the number of teeth in the gears are used instead of the diameters of the gears. For example, if the driving gear running at 100 revolutions per minute has 80 teeth, the driven must have 40 teeth if it is to run at 200 revolutions per minute and 160 teeth if it is to run half as fast as the driver.

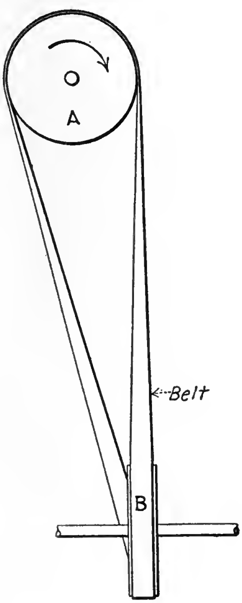


FIG. 258.

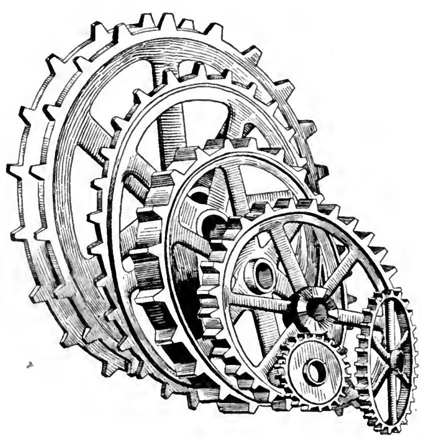


FIG. 259.

Quarter-turn Belt.—Sometimes it becomes necessary to drive by means of a belt two pulleys which are at or nearly at right angles with each other. If this must be accomplished without the use of guide pulleys, as shown in Fig. 258, certain conditions

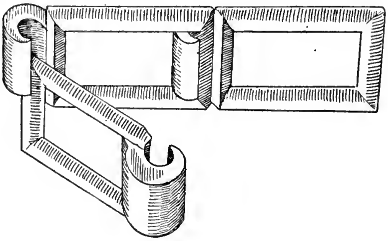


Fig. 260.

are essential. If A is the driver, the follower B must be so placed, that the belt leaving the face of pulley A will lead to the center of the face of pulley B (Fig. 258). This means that the belt must be

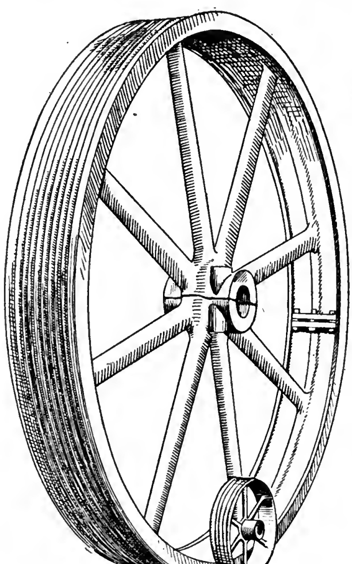


Fig. 261.

delivered from each pulley in the plane of the pulley toward which it is running. If the direction of motion of the driver is reversed, the belt will be thrown from the pulleys.

Chain Drives.—Chains made of metal are used to some extent for transmitting power. The chains run on sprocket wheels, which are provided with suitable projections (Fig. 259).

Chain drives are more positive than belt drives and will operate in damp places. The disadvantages of chain drives are that they stretch, are noisy and are expensive to keep in repair. Fig. 260 illustrates a chain drive used in connection with motors.

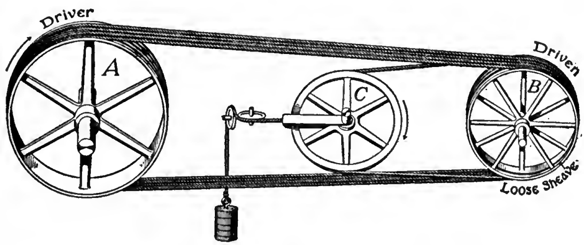


Fig. 262.

Chains for automobiles are usually supplied with rollers to reduce friction.

Rope Transmission.—Rope drives offer the following advantages for power transmission:

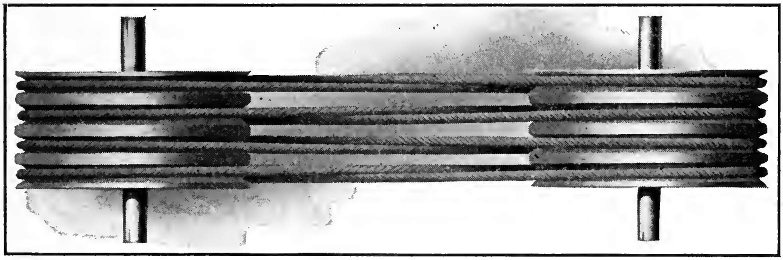


Fig. 263.

1. Power may be transmitted to much greater distances than is possible with belts.
2. Driver and driven can be very close together.
3. Power can be transmitted more readily to different floors of a building. This is advantageous in flour or cement mills.
4. Shafts of driver and driven can be at any angle with each other.

5. Drive is noiseless.
6. Loss by slipping is very small.

Hemp and cotton ropes are commonly used, these ropes running on cast-iron pulleys (Fig. 261) which are provided with grooves upon their faces to keep the ropes in place. Wire ropes are used for the transmission of large power over great distances, and in connection with hoists, elevators, inclined railways and dredging machinery.

In the United States the continuous system (Fig. 262) is most commonly used. In this case ropes are wound over the driving pulley A and driven pulley B several times. The traveling tension carriage C keeps the ropes on the pulleys at the proper tension. This system is especially well adapted for vertical and angle drives.

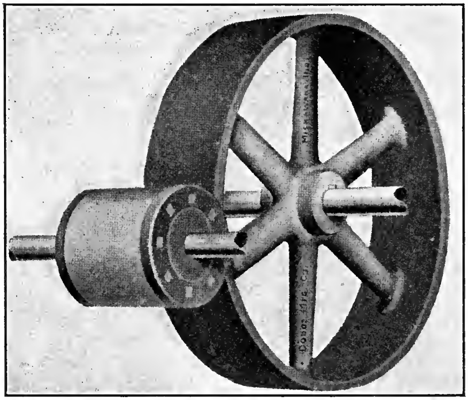


Fig. 264.

Another method is to run independent ropes side by side in grooves of pulleys (Fig. 263). This system is called the multiple system and is used to some extent for transmitting large powers, where the shafts are very nearly parallel. The continuous system (Fig. 262) has a much wider range of application than the multiple system.

Friction Gearing.—In the case of friction gearing the driver and driven are without teeth and pressed together, no belts or chains being used, and the power transmitted is due to the friction between the surfaces of the two wheels. In order to reduce the slipping to a minimum and to prevent the pressure between the two wheels from being too great, one or both of the gears are

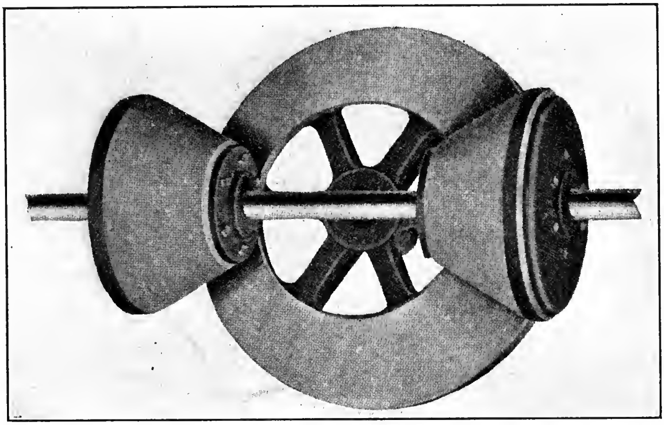


Fig. 265.

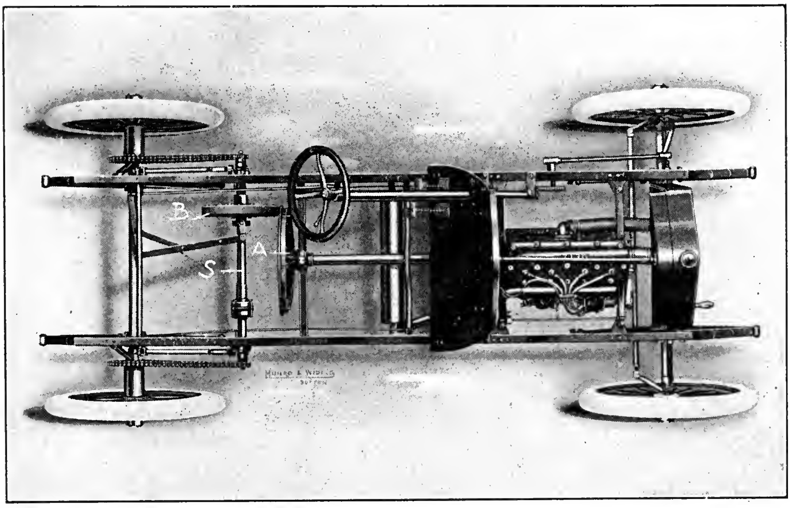


Fig. 266.

made of some slightly yielding material like wood, leather or paper, as shown in Figs. 264 and 265. If only one of the gears is made of wood or paper and the other of iron, the gear with the softer material must be the driver.

Friction gears are made as spur gears (Fig. 264) if the axes to be connected are parallel. Bevel friction gears (Fig. 265) are used for connecting axes at right angles to each other.

Another form of friction gears consists of grooves cut in the circumference of two wheels, the projections of one gear being forced into the grooves of the other.

The disc and roller constitute another form of friction gearing. If the disc revolves at a uniform speed, the speed of the roller can be increased by moving it away from the center and decreased by moving the roller toward the center of the disc. If the roller is moved past the center its motion is reversed.

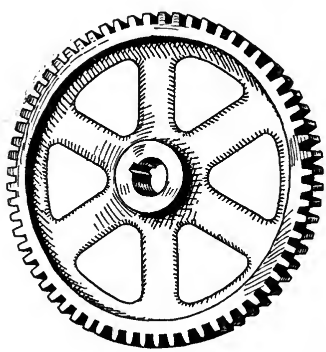


Fig. 267.

The friction drive as applied to automobiles (Fig. 266) works on the principle of the disc and roller. A flat-faced disc A is attached to the crank-shaft of the motor. The other part consists of a wheel B keyed to a shaft S parallel to the disc but free to move on the shaft. Speed changes and reversing can be accomplished by shifting the wheel on the face of the disc.

The clutches explained in Chapter VIII can also be called a form of friction gearing.

The objections to friction gears are:

1. The drive is not positive, as there must always be some slipping.

2. The transmission of power by friction gears produces excessive pressures on bearings.

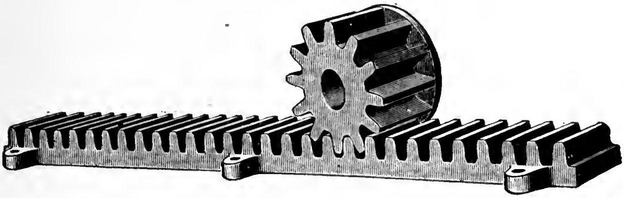


Fig. 268.

Fig. 269.

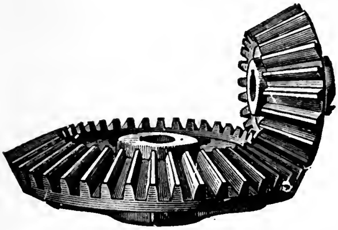


Fig. 270.

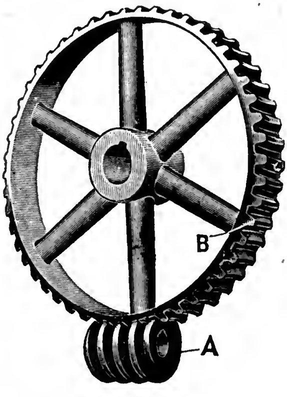


Fig. 271.

Friction gears are used where the power to be transmitted is not very great and where changes of speed have to be made while the machinery is in motion, as is often the case of certain machine tools.

Toothed Gearing.—This form of power transmission is employed when a positive speed ratio is desired between the driver and the driven.

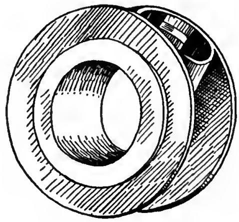


FIG. 272.

The projections of one gear which mesh with those of another are called teeth. The term "cogs" is sometimes applied to teeth inserted in the wheel of another material than that of the body of the gear.

Gears are usually made of cast iron. For rough work the gears are cast, while for accurate work cut gears, made in a special machine tool, are used. Noiseless gears are made of rawhide,

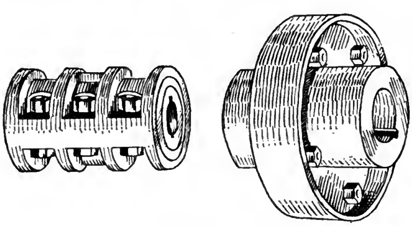


FIG. 273.

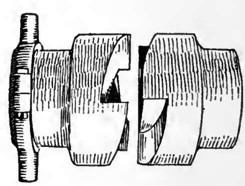


FIG. 274.

compressed between brass or iron plates. Sometimes one of the gears is provided with removable wooden teeth to decrease noise. Rawhide gears must not be used in places where they may get wet and must not be lubricated. For most farm machinery cast-iron gears are used.

Spur gears (Fig. 267) are used for transmitting power between parallel shafts. A combination of a gear meshing with teeth cut on a straight rectangular piece (Fig. 268) is called a rack and pinion. An annular gear (Fig. 269) is a wheel with teeth cut on the inside.

Bevel gears (Fig. 270) are used for connecting two axes which intersect.

In the worm and wheel (Fig. 271) the screw-like action of the worm A revolves the wheel B. The worm and wheel is used for making fine adjustments on instruments. It is also employed

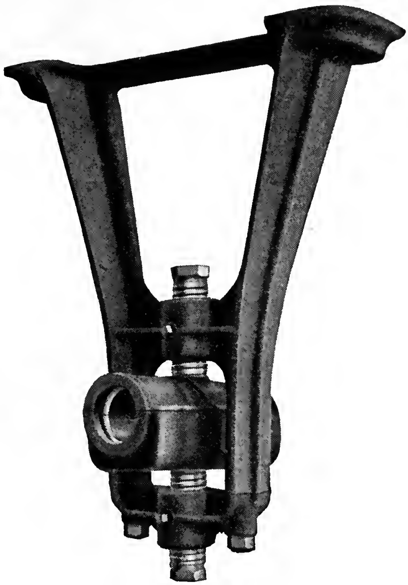


Fig. 275.

in connection with hoisting machinery, as by the proper proportioning of the screw great weights can be lifted on a drum connected on the same shaft with the worm wheel. The worm and wheel is also found on the steering mechanism of traction engines, as illustrated in Chapter VII.

Shafting.—Shafting is either employed directly for transmitting power or is used in connection with pulleys and gears.

Shafting is made of wrought iron or of steel. The better the material in the shafting, the more power it will be able to transmit. Also the greater the speed at which the shaft is run, the more power will it transmit. The torsional strength of a shaft, or the resistance which it offers to breaking by twisting, is proportional to the cube of its diameter.

To prevent a shaft from moving endwise, a collar (Fig. 272) is fastened to the shaft by means of set screws.

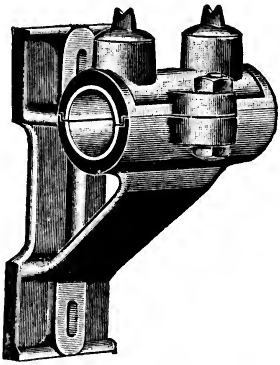


Fig. 276.

To fasten two lengths of a shaft end to end, a coupling (Fig. 273) is used. To be able to fasten or separate two lengths of shafting while they are revolving, a clutch coupling (Fig. 274) or a friction clutch, illustrated in another part of the book, should be used.

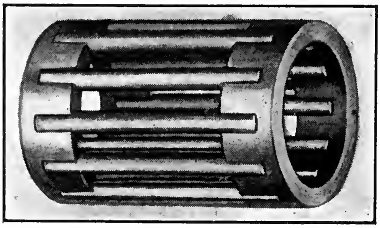


Fig. 277.

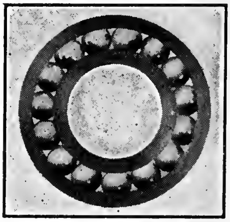


Fig. 278.

The standard sizes of shafting are given in odd sixteenths of an inch, and advance by eighths. They can be obtained from 3/16 inch up to 5 1/2 in. cold-rolled. Shafts above 5 1/2 in. are usually turned.

Shafting is suspended from hangers (Fig. 275) placed on beams, floors, or ceilings. A bracket (Fig. 276) is used for suspending shafting from walls. Hangers and brackets are provided with bearings in which the shafting revolves. The collar (Fig. 272) should be placed on the shaft against the bearing. A sufficient number of hangers or brackets should be used in order to prevent the shaft from bending.

The bearings used to carry shafting may be plain bearings, as illustrated in connection with the various types of motors. To reduce the frictional resistance of a plain bearing, a roller bearing or a ball bearing is used. In the roller bearing (Fig. 277) the shaft rolls on hardened steel roller, while in the ball bearing (Fig. 278) the shaft revolves on balls placed in suitably designed grooves. Both roller and ball bearings are expensive and difficult to keep in good order.

In general the work which can be accomplished by any motor depends not only on the quality of the motor, but also on the system used for transmitting the power of the motor to the machines where power is utilized.

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