POWER, HEATING AND VENTILATION

A TREATISE FOR DESIGNING AND CONSTRUCTING ENGINEERS, ARCHITECTS AND STUDENTS

By CHARLES L. HUBBARD, B. S., M. E.
Consulting Engineer, Boston

PART II.

POWER AND LIGHTING

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American Electrician, Chapters 1, 3.
Electrical World, Chapters 1, 2.
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Science and Industry, Chapters 1, 3.
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PART II.

POWER AND LIGHTING.

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CHAPTER I.

THEORY OF THE STEAM ENGINE.

Work.—A force or pressure acting through space produces work.

The unit of work is the *foot pound,* and is the work required to raise a weight of 1 pound 1 foot in height. Thus, to raise 100 pounds 50 feet requires $100 \times 50 = 5{,}000$ foot pounds. Neither the character of the force acting nor the direction of the movement has any effect upon the result so far as the amount of work done is concerned, provided the product of the force, times the distance moved through, is the same in each case.

Power is the rate of doing work, or the amount done in a specified time. The unit of power is the *horse power,* which is equivalent to 33,000 foot pounds per minute.

The Steam Engine.—In a steam engine steam is the agent by means of which heat is transformed into mechanical work. It is customary to speak of obtaining work from steam, but strictly speaking, it is the heat contained in the steam which produces work, and not the steam itself.

Work is obtained from steam by confining it in a closed cylinder fitted with a piston and piston rod.

Steam is admitted to one side of the piston, while the other is open to the atmosphere or connected with a condenser. The pressure of the steam forces the piston through the cylinder, driving out the air, or low-pressure steam in front of it. At the end of the stroke the admission and exhaust valves are automatically reversed and steam is admitted to the other side of the piston and drives it back to its original position.

The piston moves because the pressure on one side is greater than on the other, and in order to move, work must be done. The amount of work is easily computed, since it equals the total pressure acting on the piston, multiplied by the distance through which it moves. For example, a piston having an area of 3 square feet is acted upon by a steam pressure of 75 pounds per square inch, gauge pressure, through a stroke of 4 feet. What is the amount of work done per stroke, if the other side of the piston is open to the atmosphere? The total pressure acting upon the piston is $3 \times 144 \times 75 = 32{,}400$ pounds, and the work done equals this force multiplied by the distance through which it acts, or $32{,}400 \times 4 = 129{,}600$ foot pounds.

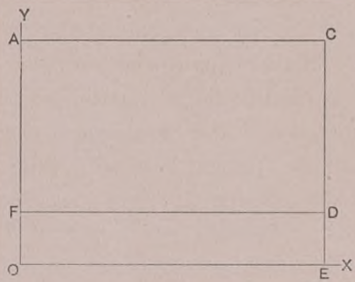


Fig. 1. Work Diagram.

Work Diagram.—The action just described may be represented graphically by the diagram shown in Fig. 1, called a work diagram. This is constructed by drawing two lines *O X* and *O Y* at right angles to each other, and letting distances measured on *O X* represent space moved through by the piston, and distances measured on *O Y*, the pressures acting. The pressure or force available for doing work in any case is the difference between the two pressures acting upon the opposite sides of the piston and is called the *effective* pressure. In computing the work done by an engine exhausting into the atmosphere, we must deduct the atmospheric pressure from the *total* steam pressure to obtain the *effective* pressure.

Returning now to the diagram, let us apply it to the example previously given.

First lay off on an assumed scale a distance *O E* to represent the stroke of the piston, which is 4 feet. Next lay off to scale

O F, equal to the atmospheric pressure per square foot acting on the piston, or $15 \times 144 \times 3 = 6{,}480$ pounds; and *O A,* equal to the total steam or boiler pressure, which is $(75+15) \times 144 \times 3 = 38{,}880$ pounds. From the definition given, the total work per stroke is equal to the pressure *O A,* multiplied by the distance *O E,* which is evidently the area of the rectangle *O A C E.* The effective pressure acting is the difference between the total and the atmospheric pressures, or that represented by the line *F A;* and the effective work done is that shown by the area *F A C D.* This rule holds true whatever the shape of the diagram.

If the pressure varies during different parts of the stroke so that the line *A C* is irregular or sloping, the enclosed area still represents the work done. In our consideration of Fig. 1, steam was admitted to the cylinder during the entire stroke, but in actual practice this is rarely done. It is customary, instead, to admit steam during only a part of the stroke and then allow it to expand, as the piston moves forward, until it fills the entire volume of the cylinder. This is shown in Fig. 2.

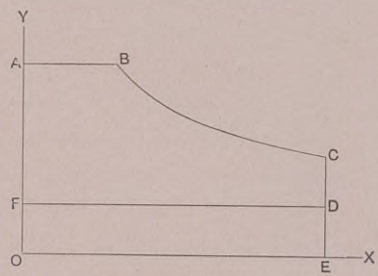


Fig. 2. Work Diagram.

Steam is admitted in this case until the piston reaches a point *B*, corresponding to one third of its stroke. Communication with the boiler is then cut off and the steam expands until it fills the cylinder, pushing the piston before it. Since there is the same weight of steam present at every point in the stroke, while the volume continues to increase, it follows that the pressure must decrease correspondingly; that is, the product of the pressure, multiplied by the volume at all points of the stroke beyond the point of cut-off, is the same in each case.

This is shown in Fig. 2. The line *A B* is horizontal because the pressure remains the same to the point of cut-off. The pressure then begins to fall, and is represented by the curved line *B C* for the remainder of the stroke.

In this case, as before, the work done is represented by the area *F A B C D*.

Mean Effective Pressure.—Whatever the form of the indicator diagram, we may always construct a rectangle having the same area and length, if we know the area and length of the diagram, for the height may be found by dividing the area by the length.

The height of this equivalent rectangle is called the *mean ordinate*, or *mean effective pressure* when applied to the indicator diagram of a steam engine.

Back Pressure.—In the example given, a back pressure was assumed equal to that of the atmosphere (15 pounds per square inch), but in practice this will vary according to circumstances. If the engine exhausts into a condenser, it will be much less, and if it exhausts into the open air a back pressure will be produced somewhat greater than atmospheric pressure, due to the friction of the steam in passing through the ports and exhaust pipe.

The *effective* pressure at any given point in the stroke is the difference between the total or boiler pressure and the back pressure, and the *mean effective* pressure is the average, or mean, of the effective pressures acting at all points throughout the stroke.

Indicator Diagram.—If steam were admitted to the cylinder at boiler pressure during the full stroke, the work done could be easily computed, since it would equal the pressure per square inch acting upon the piston, multiplied by the area of the piston in square inches, times the length of stroke in feet. We have seen, however, that the pressures upon both sides of the piston may vary under different conditions, so that in order to determine the power of an engine it is necessary to obtain a diagram like that shown in Fig. 2, giving the pressures upon both sides of the piston for all parts of the stroke.

The actual work diagram from an engine is obtained by the use of an instrument called an indicator, and the diagram is called an *indicator diagram* or card. In principle an indicator consists of a small cylinder containing a piston and rod. Steam pressure from the engine cylinder is admitted below the piston, which has a stiff spring above it. A pencil is attached to the end of the piston rod with its point resting against a paper stretched over a metal drum, which, in turn, is connected by means of a cord with the crosshead of the engine. In practice it would be

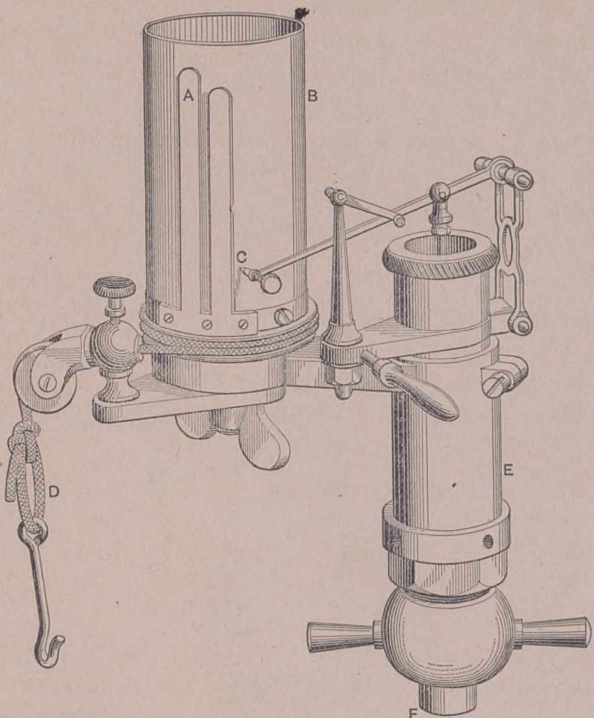


Fig. 3. Steam Engine Indicator.

impossible to represent pounds pressure by feet, or to show the actual stroke of the engine upon a diagram, so its size is reduced by attaching a reducing motion to the indicator drum, which makes the actual diagram about 3 or 3½ inches in length.

The vertical dimension of the diagram is reduced by placing a spring above the piston as already stated. These springs are usually designated as 10-pound, 20-pound, 40-pound, etc. This means that with a 10-pound spring the pencil point will be raised one tenth of an inch for each pound pressure per square inch in the cylinder, or each 10 pounds pressure will raise the pencil 1 inch. With a 20-pound spring, 1 pound pressure will raise the pencil one twentieth of an inch, and so on for any other strength of spring. Fig. 3 shows a common form of indicator.

To obtain a diagram, a strip of blank paper or light cardboard is stretched around the drum of the indicator and the actuating cord attached to the crosshead of the engine; this gives a forward and backward motion to the cord corresponding to that of the engine piston. The cock connecting the indicator cylinder with the engine cylinder is now opened and the pencil at the end of the small piston rod moves up and down distances corresponding to the pressures in the engine cylinder during different parts of the stroke. By pressing the pencil point against the card upon the drum, a *pressure line* will be traced corresponding to the line *A B C* in Fig. 2, which shows the pressures in the cylinder at all parts of the stroke.

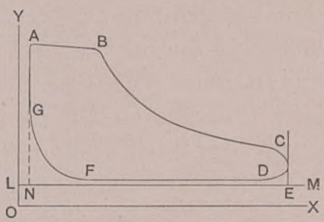


Fig. 4. Indicator Diagram.

The actual diagram varies somewhat in shape from the theoretical, as shown in Fig. 4, mainly because the valves do not open and close quickly; the ports also offer some resistance to the passage of the steam, and the back pressure is neither atmospheric in the non-condensing engine nor an absolute vacuum in the condensing. Fig. 4 represents an actual diagram taken from a non-condensing engine.

The atmospheric line *L M* is drawn by the pencil of the indicator when the connection with the engine is closed and both sides of the indicator piston are open to the atmosphere. It is the zero of the steam gauge. The admission line *G A* shows the rise of pressure due to the admission of steam to the cylinder. If steam is admitted quickly when the engine is nearly on a dead center, this line will be very nearly vertical. The steam line *A B* is drawn while the valve admits steam to the cylinder. This line is horizontal if there is no "wire-drawing" or throttling. The point of cut-off *B* indicates the closing of the admission valve; the line at this point being more or less rounded, depending upon the promptness with which the valve closes. The expansion curve *B C* shows the fall in pressure as the steam expands and the piston moves toward the end of its stroke. The point of release *C* shows the opening of the exhaust valve. The rounding is due to the slow action of the valve when opening, and because of this, release begins a little before the end of the forward stroke.

The exhaust line *C D* represents the loss in pressure which occurs while the valve opens to exhaust at the end of the stroke.

The back-pressure line *D F* shows the back pressure against which the piston acts during the return stroke. For a condensing engine this line is below the atmospheric line *L M*, the distance depending upon the state of vacuum in the condenser. For cards taken from a non-condensing engine the back-pressure line is a little above the atmospheric line. The point of exhaust closure *F* is where the valve closes to exhaust. The compression line *F G* shows the rise in pressure due to the compression of the steam remaining in the cylinder after the valve has closed to exhaust.

The line of zero pressure, or line of absolute vacuum *O X*, is drawn below and parallel to the atmospheric line a distance to scale, represented by 15 pounds pressure per square inch.

Clearance.—Clearance is the waste space at the end of the cylinder between the head and the piston when the latter is at the end of its stroke, including the counter-bore and the ports up to the face of the closed valve. It is usually expressed as a percentage of the total piston displacement and commonly varies from 8 to 12 per cent in high-speed engines, and from 2 to 3 per cent in low-speed.

The clearance line *O Y* in Fig. 4 is drawn perpendicular to the line of absolute vacuum, and at a distance from the end of the diagram equal to the percentage of the clearance volume expressed as the same percentage of the stroke.

Computing the Power of an Engine.

To accurately determine the horse power of an engine working under given conditions it is necessary to take several indicator diagrams or cards from both ends of the cylinder, then compute the work from an equal number of each and take the average of the lot.

The work per stroke is computed from an indicator card as follows: The area of the diagram, in square inches, is first measured with an instrument called a planimeter. This area is divided by the length of the diagram, in inches, to find the mean ordinate, which, multiplied by the number of the spring, will give the mean effective pressure (M. E. P.). The M. E. P. multiplied by the area of the piston in square inches, times the length of stroke in feet, gives the foot pounds per stroke. A horse power (H. P.) has already been defined as work done at the rate of 33,000 foot pounds per minute. Therefore, the work per stroke, in foot pounds, multiplied by the number of strokes per minute, divided by 33,000, equals the horse power.

Example.—An engine running at 300 revolutions per minute has a piston 12 in. in diameter and a 24-in. stroke. An indicator diagram taken with a 60-lb. spring has a length of 3 in. and an area of 2.4 sq. in. What is the horse power of the engine?

Mean ordinate $= 2.4 \div 3 = .8$.

M. E. P. $= .8 \times 60 = 48$.

The area of the piston is 113 sq. in., therefore

$$\frac{48 \times 2 \times 113 \times 600}{33{,}000} = 197 \text{ H. P.}$$

Rule for Horse Power.—The whole operation may be stated in the form of a rule as follows:

"Find the mean effective pressure by the use of a planimeter, multiply this by the area of the piston in square inches. Multiply this result by the length of stroke in feet, and the product by the number of strokes per minute. The final product divided by 33,000 will be the horse power of the engine."

A simple way to state this rule is in the form of an equation as follows:

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

in which

P = M. E. P. in pounds per square inch.

L = length of stroke, in feet.

A = area of piston, in square inches.

N = number of *strokes* per minute.

This is easily remembered because the initials of the quantities in the numerator of the second member of the equation spell the word *PLAN*.

Engine Constant.—Where a large number of cards are to be worked out, and where the speed of the engine is practically constant, it is often convenient to first compute what is known as the "engine constant."

TABLE I.

VALUES OF M. E. P. FOR DIFFERENT CONDITIONS.

Cut-off	Per cent clearance					
	0	1.75	3	5	7	9
$\frac{1}{10}$	0.330	0.354	0.369	0.392	0.413	0.432
$\frac{1}{6}$	0.465	0.481	0.492	0.509	0.524	0.538
$\frac{1}{4}$	0.597	0.607	0.615	0.626	0.636	0.646
$\frac{1}{3}$	0.699	0.707	0.713	0.719	0.727	0.734
$\frac{2}{5}$	0.766	0.771	0.775	0.781	0.786	0.792
$\frac{1}{2}$	0.846	0.850	0.852	0.856	0.858	0.862
$\frac{3}{4}$	0.966	0.966	0.966	0.967	0.968	0.969
$\frac{9}{10}$	0.995	0.995	0.995	0.995	0.995	0.995

This is found by multiplying the area of the piston by the length of stroke, and this by the number of strokes per minute, and dividing the result by 33,000. This quantity multiplied by the M. E. P. of any diagram will give the horse power as indicated by that particular card, or if it is multiplied by the average M. E. P. of all the cards it will give the average horse power for the whole test.

Computing the Approximate Power.—The approximate power of an engine may be determined without the use of an indicator diagram if the percentage of clearance, the point of cut-off, and the boiler pressure are known.

In computing the horse power by the method just given, the M. E. P. is the only factor obtained from the indicator card. By the use of Table I. this can be determined approximately for different conditions, and then substituted in the equation for horse power, after which the problem may be solved as before.

The ratios given in this table are for absolute pressures, and their use can best be shown by a practical example.

Example.—A non-condensing engine with 5 per cent clearance cuts off at ¼ stroke; the boiler pressure is 75 lb. gauge. What is the M. E. P.?

A gauge pressure of 75 lb. $= 75 + 15 = 90$ lb. absolute. The ratio for ¼ cut-off and 5 per cent clearance is 0.626; therefore the mean pressure above a vacuum is $90 \times 0.626 = 56.3$ lb.

Under ordinary conditions the back pressure on the piston of an engine exhausting into the atmosphere will be about 2 lb. above atmospheric pressure, or 17 lb. absolute, so to find the M. E. P. in the above example, we must subtract the back pressure from the mean pressure, which gives $56.3 - 17 = 39.3$ lb.

The average pressure in a condenser may be taken as about 3 lb. absolute, so that briefly we may write, M. E. P. $= [(p + 15) \times \text{ratio}] - 17$, for non-condensing engines, and M. E. P. $= [(p + 15) \times \text{ratio}] - 3$, for condensing engines, in which p is the boiler gauge pressure.

Effect of Change in Cut-off and Back Pressure.—Table I. is also useful for determining the effect upon an engine of changing the point of cut-off, or of increasing or decreasing the back pressure.

Example.—A non-condensing engine having a clearance of 3 per cent cuts off at ⅙ stroke when running under a boiler pressure of 85 lb. gauge. It is desired to increase the power of the engine 40 per cent by increasing the cut-off, all other conditions remaining the same. What will be the required point of cut-off? Absolute boiler pressure $= 85 + 15 = 100$ lb. The mean pressure ratio for 3 per cent clearance and ⅙ cut-off is 0.492, from which the M. E. P. is found to be $(100 \times 0.492) - 17 = 32.2$ lb. As the power of an engine varies directly as the M. E. P., all other conditions remaining constant, the required M. E. P. will be $32.2 \times 1.40 = 45$ lb.

Now reversing the operation, we find the mean pressure ratio to be $(45 + 17) \div 100 = 0.620$. Looking in Table I. in the column for 3 per cent clearance, we find that a ratio of 0.615, which is very close to that required, corresponds to a cut-off of ¼, which is the one to be used.

Example.—Suppose in the above case it was desired to use the exhaust steam for drying purposes under a pressure of 10 lb. gauge. What would be the resulting loss in power?

The M. E. P. for the engine cutting off at ¼ stroke and exhausting into the air was found to be 45 lb. Raising the back pressure to 10 lb. gauge or 25 lb. absolute, means a reduction in M. E. P. of $25—17 = 8$ lb.; thus giving an M. E. P. of $45—8 = 37$ lb. under the required conditions. Dividing 37 by 45 gives 0.82, which means that the resulting M. E. P., and consequently the power of the engine, would be only 82 per cent of what it was originally; that is, the power has been reduced $100—82 = 18$ per cent.

If it were necessary to keep the power the same by increasing the point of cut-off, we should proceed as in the previous example, except for an increase of 18 per cent in power instead of 40 per cent as before.

If it were desired to keep the cut-off at ¼ and bring the engine up to its original rating by raising the boiler pressure, we should proceed as follows:

Required M. E. P. $= 45$ lb.

Back pressure $= 25$ lb.

Total mean pressure $= 45 + 25 = 70$ lb.

Mean pressure ratio from Table I. is 0.615.

Required absolute boiler pressure is $70 \div 0.615 = 113$ lb., or an increase of $113—100 = 13$ lb. is required in the boiler pressure.

Mechanical Efficiency.—The preceding methods for computing the power of an engine give what is known as the *indicated* horse power (I. H. P.), and include the work required to overcome the friction of the engine itself.

The *delivered* or *brake* horse power (D. H. P.) is less than the indicated horse power, usually varying at full load from 80 to 90 per cent, depending upon the size and construction of the engine. The ratio of the D. H. P. to the I. H. P. is called the *mechanical efficiency,* and, in general, increases with the size of engine.

As the load upon any given engine is reduced, the efficiency becomes less; this is true because the friction, remaining practically constant, becomes greater in proportion to the total load as the useful or delivered work becomes less.

Thermal Efficiency.—This is the ratio of the heat transformed into work, to the total heat supplied to the engine, and depends upon the difference in temperature of the steam at initial and exhaust pressures. It is equal to

$$\frac{T_1 - T_2}{T_1}$$

in which T_1 and T_2 are the absolute temperatures of the steam at initial and exhaust pressures respectively.

Example.—What is the thermal efficiency of an engine taking steam at an initial pressure of 100 lb. gauge, and exhausting into the atmosphere under a pressure of 2 lb.

The absolute temperature of steam at 100 lb. gauge pressure is $337 + 461 = 798°$, and that of steam at 2 lb. pressure is $219 + 461 = 680°$. Therefore the efficiency is

$$\frac{798 - 680}{798} = 15\%, \text{ nearly.}$$

If the engine should be connected with a condenser, the range of temperature worked through would be greater, and the efficiency would be correspondingly increased. In actual practice this efficiency cannot be obtained because the difference between the amount of heat received and that rejected in the exhaust is not all converted into work; part of it being lost by radiation, conduction, leakage, cylinder condensation, etc. Its principal use is in showing the advantage to be gained by the higher ratios of expansion in connection with engines of proper construction.

Water Rate.—The water rate of an engine is the weight of steam required per I. H. P. per hour. This depends upon the cylinder losses already mentioned, condensation being by far the most important. During the period of exhaust the entire internal surface of the cylinder is exposed to steam at exhaust pressure, and a layer of iron of greater or less thickness is reduced to a temperature approximating that of the exhaust steam. When steam at boiler pressure is admitted at the beginning of the succeeding stroke, a certain amount of heat is given up in raising the temperature of the cylinder walls to that of the inflowing steam.

This results in the condensation of a given quantity of steam at each stroke which is a dead loss so far as useful work is concerned, but which must be included in the total amount supplied to the engine. Leakage around the valves, radiation, etc., add to

TABLE II.

WATER CONSUMPTION OF DIFFERENT TYPES OF ENGINES.

Type of engine	Pounds of steam per indicated horse power per hour	
	Non-condensing	Condensing
Simple high speed	30 to 34	22 to 26
Simple medium speed	28 " 32	21 " 25
Simple Corliss	26 " 30	20 " 24
Compound high speed	24 " 28	18 " 22
Compound medium speed	23 " 27	17 " 21
Compound Corliss	22 " 26	16 " 20
Compound Corliss of over 500 horse power	20 " 24	14 " 18

what are commonly known as "cylinder losses." These vary with different types of engines, and with other conditions to be mentioned later. Cylinder condensation increases with the ratio of expansion, for the greater the difference between the initial and final temperatures of the steam, the greater will be the cooling effect on the cylinder between the exhaust and admission periods.

The amount of heat in the steam which is actually converted into useful work is very small compared with that rejected in the exhaust and lost by radiation and condensation. For example, 1 horse power represents 33,000 foot pounds of work per minute; and the heat equivalent of this is $33{,}000 \div 778 = 42 +$ B. T. U. per minute or 2,520 B. T. U. per hour. The latent heat of steam at 100 pounds gauge pressure is 876 B. T. U., or in other words, the available heat in 2,520 ÷ 876 = 2.8 pounds of steam would be sufficient to generate 1 horse power if it could all be turned into useful work. Actually over 30 pounds of steam are required per horse power per hour in the average simple non-condensing engine, nine tenths of which is required to offset the heat carried off in the exhaust and dissipated in the various cylinder losses.

Table II., taken from Part I., gives the average water rate for different types of engines.

Multiple Expansion Engines.

We have seen that cylinder condensation is due, in the greater part, to the wide fluctuation of temperature of the interior surfaces, caused by the difference in temperature of the steam at initial and exhaust pressures. This limits the pressure under which it is economical to operate a simple engine, because after a certain point is reached the increased cylinder losses will more than offset the gain in power.

Reasons for Compounding.—If a given weight of steam is expanded through the same range of pressure in two cylinders, one exhausting into the other, instead of in a single cylinder, the resulting condensation will be considerably reduced.

This may best be shown by a practical illustration: A simple, or single-cylinder engine is supplied with steam at an initial pressure of 100 pounds gauge, and exhausts at a pressure 2 pounds above atmosphere. The range of temperature to which the interior of the cylinder is exposed is 337—219 = 118°.

Now, if two cylinders are used instead of one, and so arranged that the steam is expanded from 100 pounds pressure down to 34 pounds in the first cylinder, then exhausted into the second, and expanded down to 2 pounds, the temperature range in the first cylinder will be 337—279 = 58°, and in the second 279—219 = 60°.

The decrease in temperature range in each cylinder causes a considerable reduction in the total condensation for the entire expansion.

This holds true to a certain extent as the number of cylinders is increased to three and four.

Another advantage to be gained by multiple expansion is due to the fact that a comparatively small amount of fuel is required to raise the pressure from the common practice of 80 or 90 pounds for simple engines, to 120 or 140 pounds, which makes it possible to increase the range of expansion and thus increase the power at a relatively small cost.

It is not possible to take advantage of this with simple engines on account of excessive condensation, but by increasing the number of cylinders this obstacle is overcome and a gain is made in two ways.

Initial Pressures.—For compound engines the initial pressure may be raised to about 140 pounds, thus realizing a gain due to the higher pressure and greater expansion of from 20 to 30 per cent.

For triple expansion engines the economical pressure is of course higher than for compound, and may be increased to advantage up to 180 pounds or more. The gain in this case over the compound engine will be from 5 to 10 per cent, and even more in some cases.

Ratio of Expansion.—The best ratio of expansion depends upon the type of engine and the initial steam pressure.

For high-speed to moderately high-speed engines, such as are commonly used for driving electric generators, the following may be taken as about the average for the pressures carried:

Simple engines—3 to 4 expansions (cut-off $1/3$ to $1/4$).

Compound engines—8 to 10 expansions (cut-off $1/8$ to $1/10$).

Triple expansion engines—12 to 15 expansions (cut-off $1/12$ to $1/15$).

CHAPTER II.

TYPES OF ENGINES.

Steam engines may be classified in different ways according to their mechanical construction, although there is no definite line of distinction.

They are designed to operate at both high and low speeds, are made vertical and horizontal, and are constructed with either single or multiple cylinders, according to the requirements. They may, however, in a general way, be included under the heads of slow-speed, moderate-speed, and high-speed, and will be taken up in this order.

Slow-Speed Engines.—These are commonly characterized by speeds of 100 revolutions per minute or under, a stroke of 36 to 72 inches, independent steam and exhaust valves, the former being of the Corliss or other drop cut-off type, and are regulated by means of a fly-ball governor.

They are well adapted to factory work and for driving belted dynamos. The larger sizes are used to some extent with direct-connected machines, the latter being especially designed to operate at slow speeds.

Condensation is greater in an engine when running at slow speed than when running at high speed, because the steam remains in contact with the cylinder walls for a greater length of time at each stroke. In the case of slow-speed engines, however, this is usually more than offset by the smaller clearance and more efficient valve gears which may be employed at slow speeds, so that, as a class, this type of engine is more efficient than the high-speed.

Moderate-Speed Engines.—Following, and to some extent overlapping, the preceding type, are the medium-speed engines. These commonly run at a speed of 100 to 175 revolutions per minute, have a stroke of 24 to 42 inches, four valves positively driven, either by one or two eccentrics, side-crank construction, and automatic shaft-governor. They are adapted to locations where lack of space prohibits the use of a slow-speed engine, and where for any reason an excessively high speed would be undesirable. They are used for both power and lighting service, and may be directly connected with generators of suitable design.

High-Speed Engines.—These in most cases have a single valve, usually some modification of the slide valve, connected directly with the eccentric and controlled by an automatic shaft-governor. High-speed engines have come into general use of late years for driving electric generators, on account of the desirability of connecting the generator directly with the shaft of the engine.

This change has made it necessary to modify the general design somewhat, in order to overcome the effects of higher speeds.

The reciprocating parts must be made lighter to reduce vibration, and must be more carefully proportioned to maintain a proper balance. The bearings must be made much larger, and special care taken to keep them in adjustment.

In slow-speed engines the oil cups are easily watched, and any part of the engine can be oiled while running. This is impossible with those of high speed, and special means must be provided for supplying plenty of oil to the bearings and cylinder. Forced lubrication is often employed, with the running parts enclosed to prevent the throwing of oil.

This type of engine is made very compact, and with a short stroke as compared with those of slower speed.

Simple Engines.—This name is applied to those in which the total expansion of the steam takes place in a single cylinder. They may have one or more cylinders, but in the latter case both take steam at boiler pressure and exhaust into the atmosphere or condenser as the case may be. Simple engines cost less per horse power than compound, and are not so complicated as the latter; but on the other hand, they are more wasteful in the use of steam.

Compound Engines.—Compound engines commonly have two cylinders, so arranged that steam first enters the high-pressure cylinder, expands, and then exhausts into the low-pressure cylinder, where the expansion is completed.

Some engineers proportion the cylinders so that approximately the same amount of work is done in each, while others claim it is better to make the temperature range of the steam more nearly equal. There are various rules for determining the proper ratio between the cylinders, a simple one being to make it equal to the square root of the total ratio of expansion. For example, if the ratio of expansion is 9, the ratio of the cylinder volumes will be $\sqrt{9}=3$; that is, the volume of the low-pressure cylinder should be three times that of the high-pressure cylinder.

The most common forms of the compound engine are the *tandem* and *cross-compound.*

In the first arrangement both pistons are placed upon the same rod (see Fig. 8), with the axes of the cylinders in line. Only one set of reciprocating parts is required, and except for the two sets of cylinders, pistons and valves, the appearance is the same as that of a simple engine.

Cross-compound engines are made up of two complete machines, except the main shaft and fly-wheel, which are common to both. (See Fig. 9.) One advantage which this form has over the simple and tandem engines is that the cranks may be set at 90 degrees from each other, so that when one is on a dead center the other is at a position of nearly its greatest effort. This makes a dead center impossible and gives a more uniform turning moment.

When the cranks are set in this manner the low-pressure piston is not ready to receive steam when the high-pressure exhausts. This condition is overcome by placing a *receiver* between the two cylinders, and into which the high-pressure cylinder may exhaust and from which the low-pressure takes its supply. This is sometimes done away with by placing the cranks either in the same position or opposite, so that the strokes begin and end together. In this case the steam exhausts from the high-pressure cylinder directly into the low-pressure; but when this is done, the advantage of a uniform turning moment is lost.

Cross-compound engines are more expensive to make, and require a larger floor space than tandem engines, while the labor of cleaning and oiling is nearly doubled. On the other hand, the individual parts may be made lighter and are thus more easily handled.

Triple Expansion Engines.—In engines of this form the steam is expanded in three stages instead of two. Three cylinders are usually employed, the high, intermediate, and low, with the cranks 120 degrees apart.

Sometimes four cylinders are used instead of three, the volume of the low-pressure cylinder being divided into two, which gives a better balance. Triple expansion engines are more frequently employed in marine work and large pumping stations, and are not well adapted for use in connection with heating plants, being more expensive and complicated than would be warranted by the gain in economy.

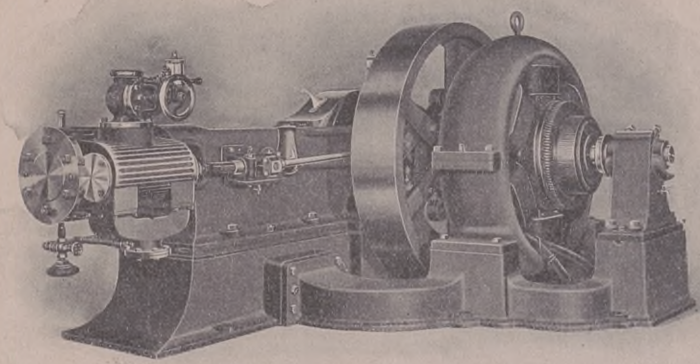


Fig. 5. Simple High-speed Engine.

Descriptions of Engines of Different Types.

The Harrisburg Standard engine, shown in Fig. 5, is a good illustration of a simple high-speed engine. This is shown fitted with a direct-connected generator.

Table III. gives the power and the approximate floor space required by some of the different sizes of the belted pattern.

The horse powers given in the table are for 80 pounds initial pressure and ¼ cut-off, which may be taken as average conditions for engines of this type.

For determining the width of a direct-connected engine and generator, we may, in general, add the width of the "engine type" of generator to that of the belted engine. This is a safe rule to follow, but in many cases will give a dimension somewhat greater than the actual width. Table III., and similar ones which follow, are for approximate use only, and should be supplemented by actual prints obtained from the makers. Neither do they give a complete list of the different sizes of the type of engine shown. Like the tables of dimensions given for special makes of boilers

TABLE III.

DIMENSIONS AND FLOOR SPACE OF HARRISBURG STANDARD BELTED TYPE ENGINES.

Simple non-condensing, 80 pounds pressure, ¼ cut-off

Diameter of cylinder	Stroke	Revolutions per minute	Indicated horse power	Diameter of steam pipe	Diameter of exhaust pipe	Floor space belted type
In.	In.			In.	In.	Ft. In. Ft. In.
5	8	425	15	2	2	3 10 by 6 10
7	8	425	26	2½	2½	3 10 " 6 10
8	9	400	35	3	3	3 10 " 7 0
9	10	350	45	3	3	4 8 " 7 10
11	10	350	65	3½	3½	4 8 " 7 10
12	11	325	80	4	4	4 8 " 8 0

and other apparatus, they are furnished as guides to show the approximate space required for different designs, and are for the use of architects and engineers in proportioning the size of an engine room where the particular make of machine is not specified, but where the general *type* to be employed is known.

Fig. 6 shows the Westinghouse Standard engine, with direct-connected generator. This is a vertical, single-acting, simple engine with two cylinders.

In single-acting engines, the steam is admitted only to the head end of the cylinder, the other being open to the atmosphere. The advantages claimed for this type of engine are that the pressure upon the moving parts is always in the same direction, and the bearings are less likely to wear loose, also the valve arrangement is simplified. Table IV. gives a partial list of these engines with ratings at 80 pounds pressure. They may be connected with the generator in two ways. That shown in the cut is the more compact, one of the pulleys being removed and special bearings and supports provided to receive the generator upon the same bed-plate. In the second arrangement the generator is

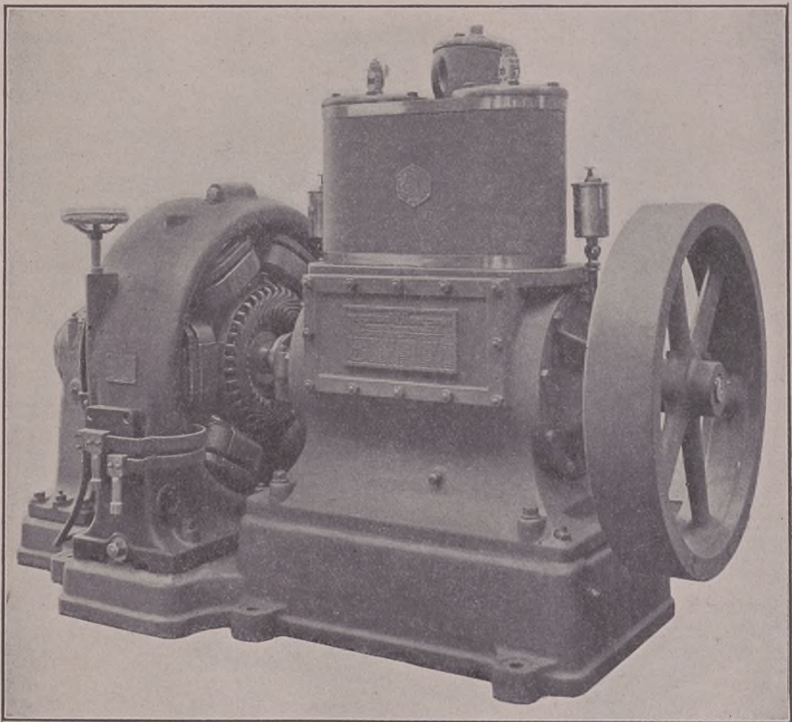


Fig. 6. Vertical High-speed Engine.

attached to the end of the shaft by means of a flexible coupling, and no change is made in the engine. The engine and generator may stand upon the same or separate bed-plates as desired.

Fig. 7 illustrates an engine of the slow-speed Corliss type, made by the Allis-Chalmers Company. These engines are used for driving dynamos as well as for factory and general power pur-

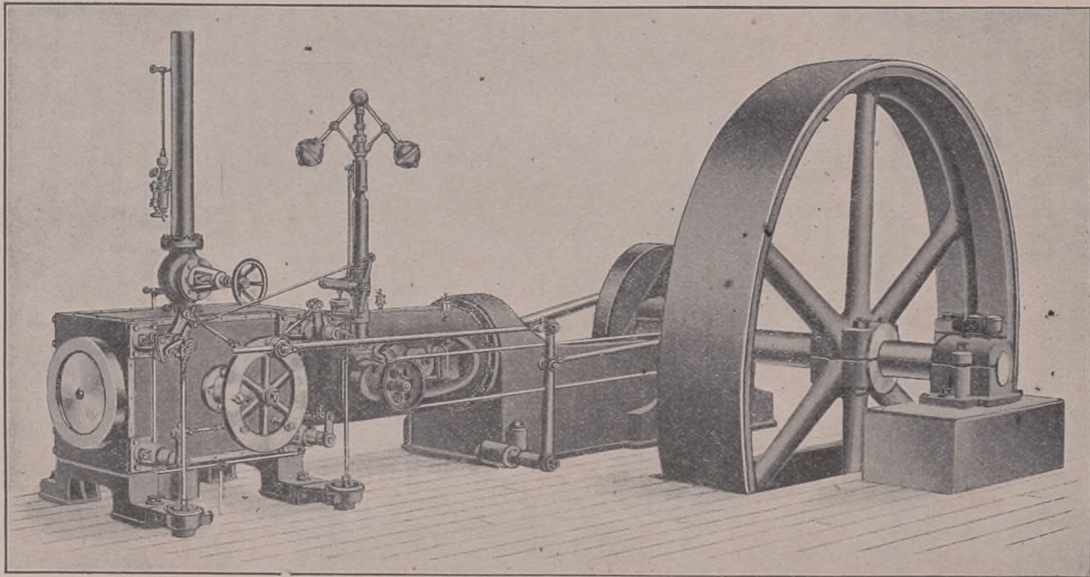


Fig. 7. Slow-speed Simple Corliss Engine.

poses; they may be either belted or direct-connected as conditions require. In the latter case, however, the speed is seldom reduced below 80 or 90 revolutions per minute. The following table gives the rating of a few of the small and medium sizes working

Table IV.

Dimensions and Floor Space of Westinghouse Engines, Belted Type.

Simple non-condensing, 80 pounds pressure

Diameter of cylinder	Stroke	Revolutions per minute	Indicated horse power	Diameter of steam pipe	Diameter of exhaust pipe	Floor space belted type
In.	In.			In.	In.	Ft. In. Ft. In.
$6\frac{1}{2}$	6	400	15	2	2	2 6 by 5 5
$8\frac{1}{2}$	8	400	35	3	3	3 0 " 6 8
11	10	330	60	4	4	4 0 " 8 0
$13\frac{1}{2}$	12	300	100	6	6	5 0 " 9 9
$15\frac{1}{2}$	14	300	150	6	6	6 6 " 11 0
20	16	250	250	8	10	6 6 " 11 6

Table V.

Dimensions and Floor Space of Corliss Engines, Belted Type.

Simple non-condensing, 90 pounds pressure, $\frac{1}{4}$ cut-off

Diameter of cylinder	Stroke	Revolutions per minute	Indicated horse power	Diameter of steam pipe	Diameter of exhaust pipe	Floor space belted type, belted away from cylinder
In.	In.			In.	In.	Ft. In. Ft. In.
12	30	90	74	4	5	8 8 by 18 6
18	36	80	177	6	7	10 0 " 22 10
20	48	72	263	7	8	10 10 " 29 8
24	48	70	368	8	9	12 8 " 31 2
26	60	65	502	8	10	12 8 " 36 8
30	60	62	637	10	12	14 11 " 39 4

under 90 pounds steam pressure. The standard sizes run up to over 2,700 H. P. at 140 pounds pressure.

A typical form of the tandem compound engine is shown in Fig. 8, which illustrates the McEwen engine built by the Ridgway Dynamo and Engine Company.

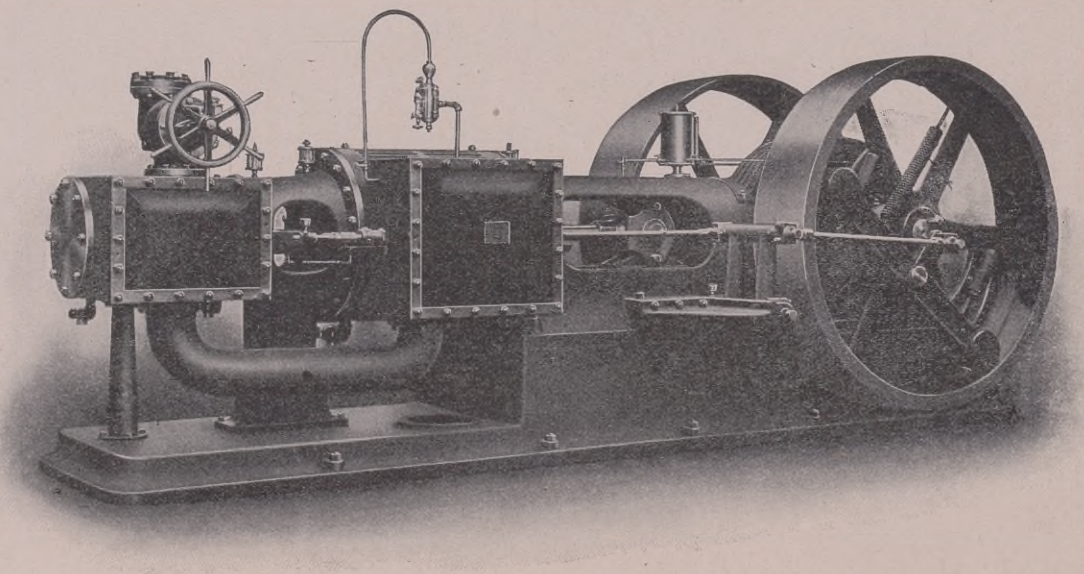


Fig. 8. Tandem Compound Engine.

Table VI. gives the rating of a number of different sizes working under a steam pressure of 100 pounds. The dimensions given are for the belted type, and are for cylinder ratios of 1 to 4.

The Ball engine shown in Fig. 9 is of the cross-compound type.

Table VI.

Dimensions and Floor Space of Tandem-Compound Engines, Belted Type.

Compound non-condensing, 100 pounds pressure

Diameter of high pressure cylinder	Diameter of low pressure cylinder	Stroke	Revolutions per minute	Indicated horse power	Diameter of steam pipe	Diameter of exhaust pipe	Floor space belted type
In.	In.	In.			In.	In.	Ft. In. Ft. In.
8	16	12	275	75	3	7	5 0 by 12 8
9	18	14	250	105	4	8	5 6 " 15 1
10	20	16	225	135	4½	9	6 6 " 16 7
12	23	18	200	200	4½	10	7 0 " 18 11
14	28	20	180	250	6	12	7 6 " 19 6
16	32	22	165	350	7	14	8 6 " 20 6

Table VII.

Dimensions and Floor Space of Cross-Compound Medium-Speed Engines, Belted Type.

Compound non-condensing, 120 pounds pressure

Diameter of high pressure cylinder	Diameter of low pressure cylinder	Stroke	Revolutions per minute	Indicated horse power	Diameter of steam pipe	Diameter of exhaust pipe	Floor space direct connected type
In.	In.	In.			In.	In.	Ft. In. Ft. In.
20	32	24	150	450	8	14	21 6 by 19 0
22	34	27	150	600	8	14	23 0 " 20 6
24	38	27	150	750	9	16	24 0 " 21 0

The particular engine shown is of moderate speed, with Corliss valves arranged for positive action, and is combined with a direct-connected generator.

Table VII. gives ratings and dimensions of several sizes of the

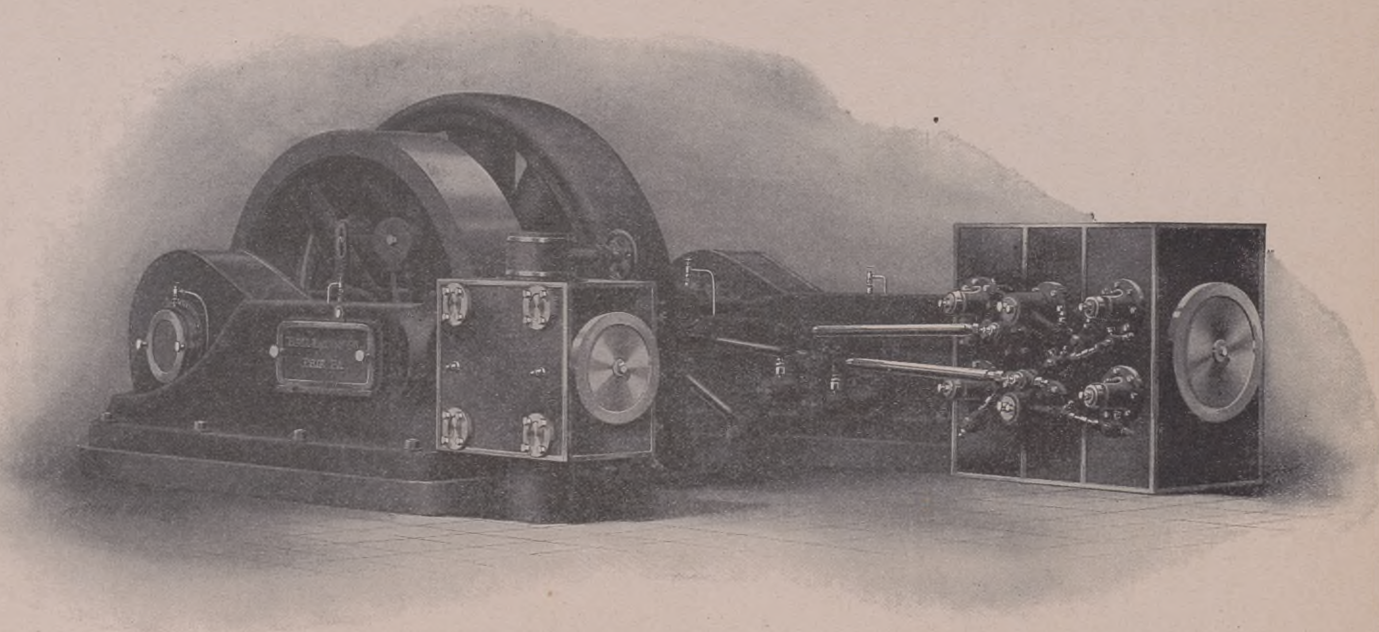


Fig. 9. Cross-compound Medium-speed Engine.

direct-connected type working under a steam pressure of 120 pounds.

Fig. 10 shows a different form of compound engine, the American Ball engine, and known as a duplex-compound.

In this arrangement the high-pressure cylinder is placed directly below the low-pressure as shown, and the two piston rods are joined to the same crosshead. The remaining portion is the same as for a simple engine.

The advantage of this over other forms is its compactness, as it requires practically no more space than a simple engine of equal stroke. The cut shows it in combination with a direct-connected generator. Table VIII. gives the ratings and dimensions of several sizes of the belted type working under 100 pounds steam pressure.

Table VIII.

Dimensions and Floor Space of American Ball Engines, Duplex Compound, Belted Type.

Compound non-condensing, 100 pounds pressure

Diameter of high pressure cylinder	Diameter of low pressure cylinder	Stroke	Revolutions per minute	Indicated horse power	Diameter of steam pipe	Diameter of exhaust pipe	Floor space belted type				
In.	In.	In.			In.	In.	Ft.	In.		Ft.	In.
9½	15	11	290	80	3½	5	5	1	by	9	9
11½	18½	12	280	120	4	6	5	10	"	10	10
13	20	14	250	160	4½	7	6	7	"	12	0
14	22	16	230	200	5	8	7	1	"	13	1
16	25	16	220	250	6	9	7	8	"	13	8
18	28	18	200	325	6	10	8	7	"	15	0
20	32	18	190	400	7	12	9	2	"	15	4

The Steam Turbine.

Advantages.—Although made in smaller sizes, the use of the steam turbine in this country, up to the present time, has been confined principally to the driving of generators in large power plants. While there is no mechanical difficulty in its being operated non-condensing or at moderate pressures, the best effi-

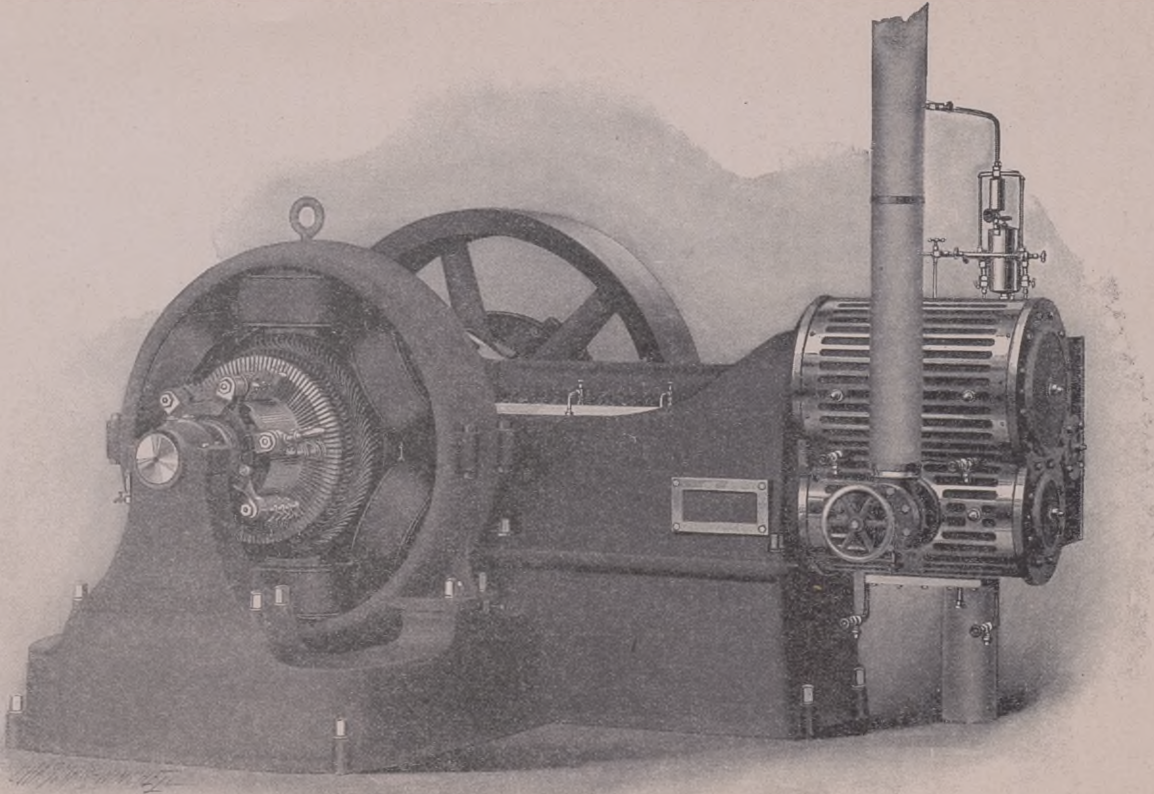


Fig. 10. High-speed Compound Engine.

ciency is secured when supplied with steam at a high initial pressure and run condensing.

Its desirability for isolated plants of small or moderate size, and especially those in which the exhaust steam is utilized for heating purposes, has not yet been fully demonstrated, and can only be determined after careful trial under actual working conditions.

Turbines, owing to their high speed and uniform efficiency under a considerable variation in load, are particularly adapted to the driving of electric generators, to which they may be directly connected. They require small foundations and take up little space, and owing to the small number of moving parts, the friction is slight.

Another advantage is the ability to use highly superheated steam, as no lubricating oil is required, and as the same parts of the interior are always exposed to steam of practically the same temperature, the loss from condensation is small.

The steam consumption of turbines is about the same as that of the best reciprocating engines, having been gradually reduced by various improvements in their construction.

Where a slow speed is required, the reciprocating engine is probably the better; and how far the turbine will supersede the older type of engine can only be shown by future developments.

Principle of the Turbine.—The principle upon which a turbine acts is different from that of a reciprocating engine. It does not derive its power from the static force of steam expanding behind a piston, but instead, the expansion produces a high velocity in a jet of steam. which is made to strike the vanes of a revolving wheel and thus give up its kinetic energy in turning the wheel and so producing work.

The jet must strike the vanes without shock, and leave them with as low an absolute velocity as possible.

There are several makes of turbines upon the market, among which the De Laval, Westinghouse-Parsons, and the Curtis are good illustrations.

De Laval Turbine.—The wheel of the De Laval turbine is shown in Fig. 11. This consists of a hub and disk with suitably shaped vanes or blades around the outer edge. The blades are surrounded by a casing, which prevents the escape of the steam until it has done its work. A piece of the casing has been cut away in Fig. 11 to show the form of the blades. There are usually four nozzles which supply steam to the turbine, one of which is shown in section.

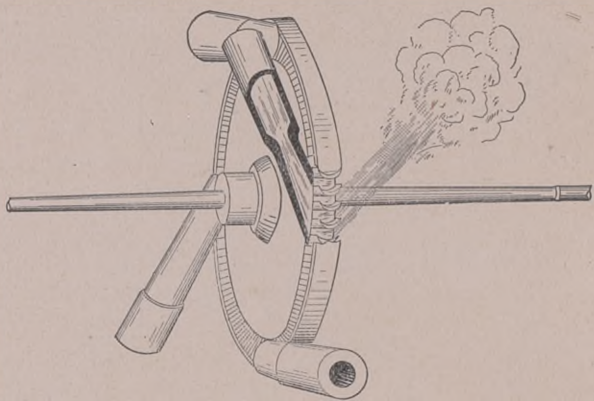


Fig. 11. De Laval Wheel and Nozzles.

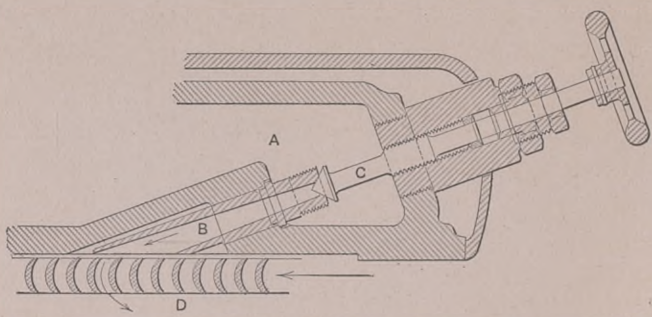


Fig. 12. Nozzle and Valve.

Principle of De Laval Turbine.—In action, steam strikes the blades and is deflected; the impact of the jet and the reaction due to its deflection cause the wheel to rotate rapidly. The nozzles are small at the throat and diverge outward. By making them of the right length and with the proper amount of divergence, the steam can be expanded from the pressure of admission to that of the condenser. Complete expansion is obtained in the diverging nozzle, and the steam leaves it at the exhaust pressure. The steam then works only by virtue of its high velocity.

Construction.—Fig. 12 shows a section through a portion of the steam chamber surrounding the wheel, and one of the nozzles with its valve for adjusting the flow of steam.

This turbine has a long flexible shaft which can deflect enough to make up for any eccentricity of the center of gravity of the revolving parts.

The high speed of the wheel is reduced by means of especially constructed spiral gears running in oil inside of an enclosed casing. Speed regulation is obtained by means of a throttle valve in the admission pipe controlled by a fly-ball governor.

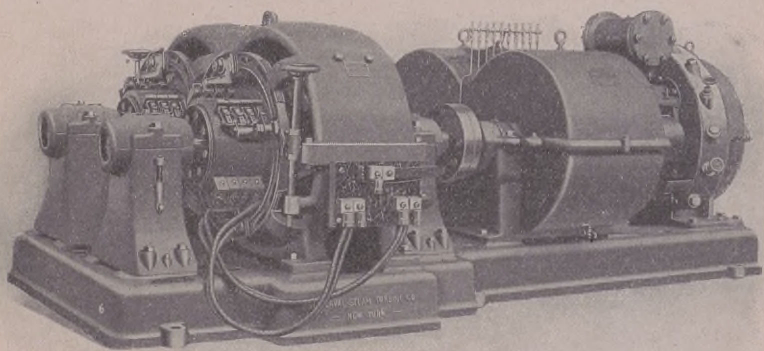


Fig. 13. De Laval Generating Set.

Fig. 13 shows the exterior of a De Laval steam turbine with direct-connected dynamos. The chamber surrounding the wheel is shown at the right; in the center is the casing containing the speed reducing gears, and at the left the dynamos. In generating sets of larger sizes as shown the pinion of the turbine shaft meshes with a pair of large gears and these in turn drive duplex dynamos.

Westinghouse-Parsons Turbine.—Fig. 14 is a longitudinal section through the Westinghouse-Parsons turbine..

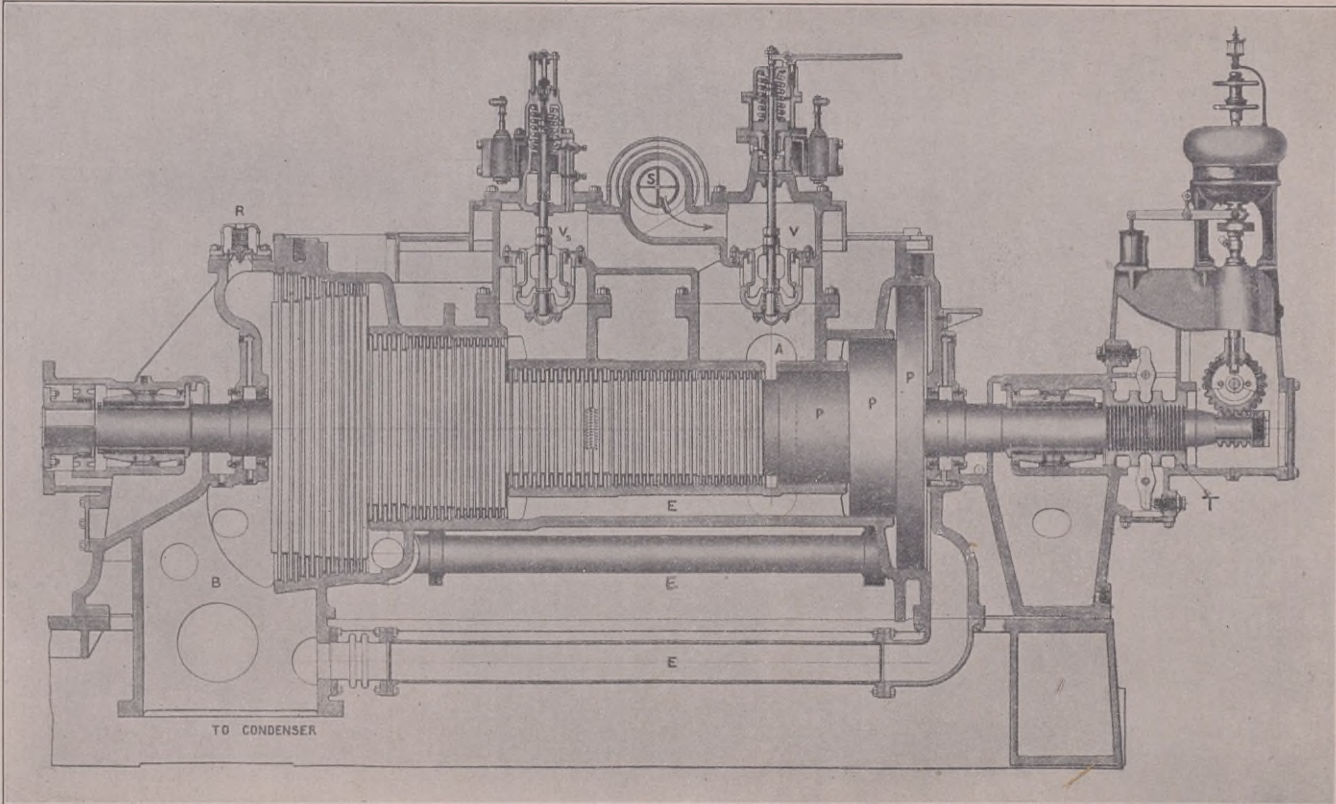


Fig. 14. Section through Westinghouse-Parsons Turbine.

In this machine the reaction and impulse principles are combined by using a rotating drum on which there is a series of rings or blades, alternating with rings of stationary blades between them, which are attached to the casing. In Fig. 14 the moving blades are shown as rings encircling the enlarged shaft or drum of the turbine, while the stationary blades appear as teeth or projections between them. Both the stationary and movable rings are made up of crescent-shaped blades or vanes similar to those around the outer edge of the De Laval wheel. The relation borne by the moving blades to the stationary blades is shown more clearly in Fig. 15, where the direction of the steam is indicated by arrows.

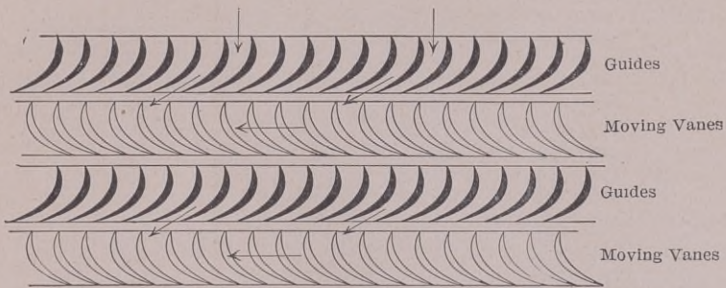


Fig. 15. Diagram of Blades.

Steam enters between the fixed blades and is deflected against the wheel blades beyond, driving them around and giving the impulse effect; then with but little loss in pressure it blows backward with nearly the same force on the farther side, and thus produces the reaction effect. The office of the stationary blades is simply that of deflectors to change the direction of the flow of steam coming from one row of moving blades and direct it toward the next.

Steam is admitted to the chamber *A* through the governor valve, and passes through the blades as above described, to the exhaust chamber *B*. As it passes the different sets of blades, the volume of the passage is increased by enlarging the diameter of the drum and the height of the blades to correspond with the expansion of the steam. In the De Laval turbine the steam is entirely expanded before reaching the wheel, but in this type expansion is accomplished in the machine itself.

Balance Pistons.—In order to reduce the thrust which would result from the endwise pressure of the steam as it passes toward the exhaust, equalizing pistons *P, P, P* and passages *E, E, E* are provided. These pistons have the same areas as the enlarged portions of the shaft, and being exposed to the same pressures through the equalizing passages, a balance is maintained.

Speed Regulation.—Steam enters the turbine in puffs, not in a continuous blast. Speed regulation is, therefore, accomplished by proportioning the duration of the puffs to the load. This is done by means of a small pilot valve actuated directly by the governor and which controls the steam supply through the main poppet admission valve. When the turbine is in operation the main poppet valve *V* is continually opening and closing at uniform intervals, but the periods during which the valve is allowed to remain open are proportioned to the load on the turbine. At light load the valve opens for a very short period and remains closed during the greater part of the interval. As the load increases the period lengthens until finally, at about full load, the valve does not reach its seat at all and continuous pressure is obtained in the high pressure end of the turbine. On the load becoming further increased an auxiliary or secondary valve *Vs* begins to open and to admit steam to the annular space at the beginning of the intermediate drum of the rotor where the working steam areas are greater. This increases in proportion to the total power of the turbine. The operation of this secondary poppet valve is the same as that of the main admission valve, so that the governor automatically controls the power and speed of the turbine from no load to such overloads as are usually beyond the limits of generating apparatus built on normal ratings.

The governor is of the fly-ball type, the ball levers being mounted on knife edges instead of pins to secure sensitiveness.

The Curtis Turbine.—This employs a combination of the principles involved in the De Laval and Parsons machines.

A nozzle is used to partially expand the steam, the remainder taking place as it passes through the wheel, and thus overcoming any retardation which might occur, due to the friction between the steam and the blades.

The best results with a jet turbine are obtained by having the peripheral velocity of the wheel about half the velocity of the steam jet. When, as must always be the case, a turbine wheel runs at a speed less than this, the steam will have a residual velocity as it leaves the wheel; and the slower the wheel runs the greater will be the residual velocity, and the resulting waste of energy. In the Curtis turbine a modified form of the De Laval nozzle is used, the wheel is run at a comparatively low speed, and the residual velocity of the exhaust steam is used to run a second wheel on the same shaft, thus making a compound machine.

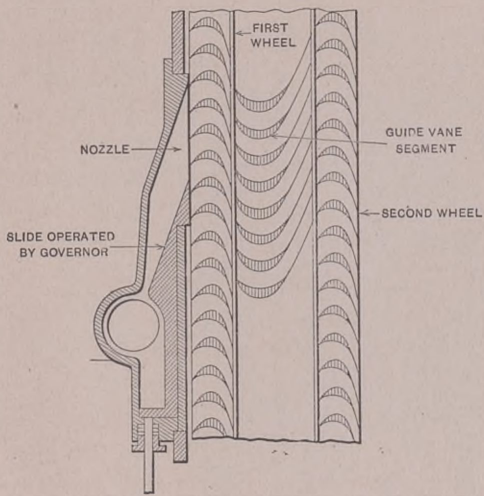


Fig. 16. Illustrating Principle of Curtis Turbine.

Constructive Features.—In its simplest form the Curtis turbine consists of two rings of curved buckets mounted upon discs revolving with the shaft. Between the two revolving rings is a group of curved blades in the form of a short segment fixed to the interior of the turbine case. The nozzle is of rectangular cross section, so designed that one side of it can slide under the action of the governor without altering the ratio between the inlet and outlet area of the nozzle, as illustrated in Fig. 16. By

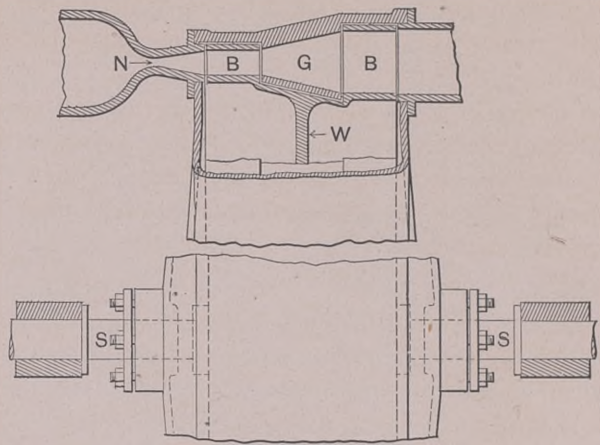


Fig. 17. Longitudinal Section of Blades, Single Stage Turbine.

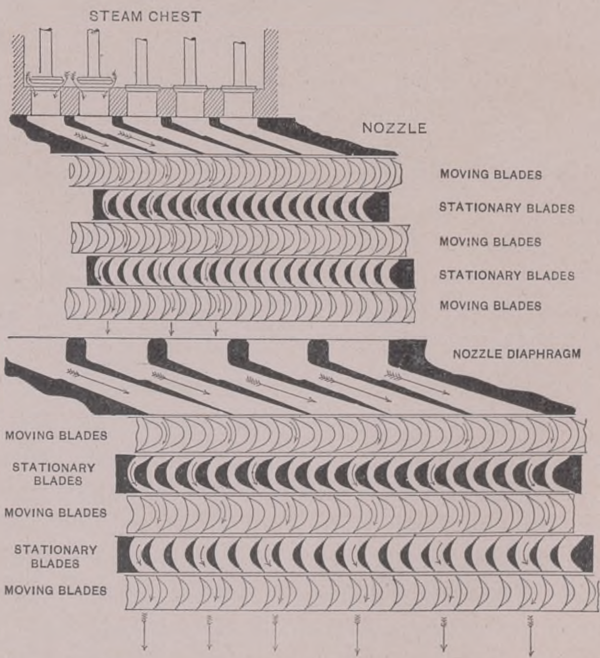


Fig. 18. Cross Section of Blades, Multiple Stage Turbine.

this means the quantity of steam delivered is adjusted to suit the load. The arrangement of the fixed and movable blades is more clearly shown in Fig. 17.

Steam enters in the direction of the arrow, passes through the nozzle and the constantly increasing space between the blades. *B B* are the wheel blades, rotating together on the same shaft. *G* represents the intermediate stationary blades, and at the right is the exhaust passage.

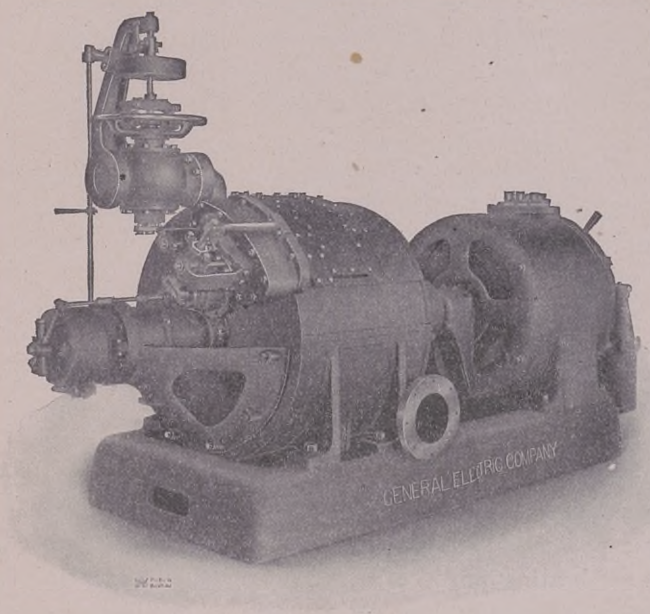


Fig. 19. 75 Kw. Curtis Turbine Generating Unit.

In its practical form, instead of there being a single nozzle, there are several ranged in a row, and instead of two sets of blades there is provision for several stages of expansion. This arrangement is shown diagrammatically in Fig. 18. Steam enters through the series of nozzles, forming a broad belt, and the quantity admitted is regulated by a series of poppet valves, one for each nozzle. Regulation is effected by opening or closing these valves automatically, and for fine regulation, involving a less quantity of steam than flows through a single nozzle, throttling is resorted to in one of them.

The wheel of the Curtis turbine in the larger sizes is usually mounted with its shaft in a vertical position, and in direct-connected generating sets the dynamo is placed at the top.

Fig. 19 shows a 75-Kw. horizontal generating set equipped with a Curtis turbine, and Table IX. gives the over-all dimensions of some of the standard sizes of this type.

These turbines can be arranged for either condensing or non-condensing operation as desired.

TABLE IX.

OVER-ALL DIMENSIONS OF CURTIS TURBINES.

Rating	Voltage	Speed, revolutions per minute	Length	Weight, pounds
15 Kw.	85	4000	5 ft. 6 in.	1850
25 "	125 to 250	3600	6 " 0 "	3600
75 "	125 " 250	2400	13 " 0 "	12000
150 "	125 " 250	2000	16 " 0 "	25500
300 "	125 " 250	1500	17 " 0 "	30000

The Selection of a Steam Engine.

The selection of an engine for any particular location depends upon the conditions under which it is to operate. For sizes under 100 horse power, and especially where the exhaust steam is to be used for heating purposes, the simple non-condensing engine is generally used. For larger sizes, and where the steam pressure is over 120 pounds, the compound engine is often advocated upon the ground of economy.

The first cost of a compound engine is considerably more, being perhaps 30 per cent greater for the average machine. The steam consumption in the case of high-speed non-condensing engines at full load, is from 20 to 30 per cent less for the compound, while the increase in fuel consumption required to raise the boiler pressure from 80 to 125 pounds is only about 1 per cent. When all of the exhaust is used for heating, there is of course nothing to be gained by installing a high-priced engine for the sake of reducing the steam consumption. But on the other hand if the exhaust can only be used for a comparatively small part of the year, or if but a portion of it can be utilized in the heating system, then the saving will often offset the interest and depreciation changes upon the additional first cost and leave a good margin of profit besides, this being especially true in localities where the cost of fuel is high.

Simple vs. Compound Engines.—In making a comparison between the simple and compound engine for any given case, it is necessary to first compute the "annual fuel cost" of each. This should include the additional fuel, if any, required for heating, and also the interest and depreciation charges upon the first cost. The method of doing this may be illustrated by a practical example:

Example.—The power for lighting and elevator service in an office building is to be furnished by two high-speed non-condensing engines of 100 horse power each. They are both to run 12 hours per day for 300 days in the year, and the steam required for heating averages 60,000 lb. per day for 100 days. Which will be the more economical, simple engines costing $15 per horse power and having a water rate of 32 lb. per horse power per hour, or compound engines at $20 per horse power and a water rate of 25 lb. per hour?

Let the cost of coal be $4 per ton of 2,000 lb. and assume an evaporation of 8 lbs. of steam per pound of coal in the boilers. Then for the simple engine, the fuel cost for power will be

$$\frac{32 \times 200\ (12 \times 300) \times 4}{8 \times 2{,}000} = \$5{,}760$$

per year. To this must be added an interest charge of 4 per cent, and a depreciation of say 8 per cent on the first cost, which is $200 \times 15 \times 0.12 = \$360$.

The next step is to see if any additional fuel is required for heating. The average requirements are 60,000 lb. of steam per day, or 5,000 lb. per hour. Assuming that 80 per cent of the steam delivered to the engines is available for heating in the form of exhaust, there will be $200 \times 32 \times 0.8 = 5{,}120$ lb. furnished in this manner, which is more than is required for heating, so that no extra charge is necessary for this purpose. The total fuel cost for the simple engines is therefore $5,760 + 360 = \$6,120$.

Taking the case of the compound engines, all of the factors remain the same except the water rate and first cost. As the expenditure for fuel is directly proportional to the water rate of the engine, the amount in this case will be $\$5,760 \times 25/32 = \$4,500$. Interest and depreciation $200 \times 20 \times 0.12 = \$480$.

The available exhaust for heating is $200 \times 25 \times 0.8 = 4,000$ lb. per hour, which is 1,000 lb. less than is required. If 8 lb. of steam are evaporated per pound of coal, then $1,000 \div 8 = 125$ lb. of coal are required per hour to provide the steam necessary for heating, over and above that furnished by the engines in the form of exhaust. This for 1,200 hours at \$4 per ton is

$$\frac{1,200 \times 125 \times 4}{2,000} = \$300$$

From the above we find the total fuel cost to be $\$4,500 + 480 + 300 = \$5,280$, against \$6,120 in the previous case, making a saving of $\$6,120 - 5,280 = \$840$ per year in favor of the compound engine.

As the compound uses less steam than the simple engine, the boiler power can be reduced if the plant is a new one. Steam per hour for simple engine, $200 \times 32 = 6,400$ lb. Steam per hour for compound engine, $200 \times 25 = 5,000$ lb., resulting in a saving of 1,400 lb. per hour.

Assuming an approximate evaporation of 30 lb. of steam per boiler H. P., a reduction of $1,400 \div 30 = 47$ H. P. can be made in the size of the boiler plant.

If water-tube boilers are used at a cost of say \$20 per H. P. this would result in a saving of $20 \times 47 = \$940$ in the first cost, or a yearly saving of $940 \times 0.12 = \$112.80$; which, added to \$840, makes a total of \$952.80 per year by the use of compound engines under the conditions stated in the problem.

Allowance for other Conditions.—This however is only a simple illustration of the method of computing fuel costs; other conditions might be present which would alter the result, such as excessive water rates, or increased cost of attendance for the compound engines.

We have also assumed, for simplicity, that both engines would operate at full load all of the time, which would probably not be the case in actual practice. Then again, the quantity of steam required for heating at different seasons might vary from that given in the example. However, the illustration shows the general method of procedure, and can be varied to suit existing conditions.

Use of Compound Engines.—Compound engines have been growing in favor of late years for use in connection with heating systems, and in many cases have shown their superiority when "all-the-year-round" economy is considered. There may be a period during the coldest months when no gain is shown over the simple engine, but when the milder weather of spring and fall is considered, together with the summer months, when no use can be made of the exhaust steam except for heating the feed-water, the economy of the compound engine becomes evident. The main point is to always operate the compound unit within its economical range, that is, from 50 per cent load to full load, as at light loads the gain falls off quite rapidly.

Selection and Installation.

The best type of engine as regards speed, depends much upon the available room. In office buildings and other similar locations where floor space is valuable, the high-speed engine is used almost exclusively.

For central lighting plants in connection with public institutions, where space is not so limited, the moderate-speed engine is a good type to employ.

For factory and general power work, the slow-speed engine ot Corliss or similar design is generally used, being economical in the use of steam, durable, and easily cared for.

Details of the Steam Engine.—No attempt will be made to go into the details of construction, as they vary so widely in different makes.

It is customary for the engineer to first decide upon the type of engine best adapted to the needs of any particular case, and then make a study of the mechanical construction of several standard makes fulfilling the requirements. This can be done from cuts and drawings furnished by the makers, supplemented, when possible, by an examination of similar engines already installed.

Foundations.—Detail drawings of the foundations are usually furnished by the builders of the engine. Care should be taken not only to make the foundations stable, but to construct them so that no vibration will be transmitted to adjoining rooms and buildings. A loose or sandy soil does not carry such vibrations as readily as a firm earth or rock. There are various ways of preventing the transmission of vibration, the most common of which is to make the excavation from 2 to 3 feet greater than the foundations in all directions, and fill in the space with well packed sand.

Both brick and concrete are used for the foundation itself and this is usually capped with hammered stone in the best class of work when brick are used.

The anchor bolts are held in place during the construction of the foundation, by means of a wooden template which insures their correct position. They are commonly run inside of iron pipes with an internal diameter a little larger than the bolt; this allows a certain amount of play and is convenient for the final alignment of the machine. The lower ends of the bolts are provided with heavy iron plates or washers embedded in the masonry.

Generators are usually mounted on a wooden base to furnish insulation for the frame.

Data relating to the safe loading of different soils has already been given in connection with boiler and chimney foundations; and this applies in a general way to the foundations for engines and generators, although in this case vibration must be provided for in addition to the load itself.

For units of 200 Kw. and less it is customary to start with a footing of concrete 12 inches to 20 inches in thickness and of an area to be governed by the nature of the soil. If the foundation is to be of brick, it should have a batter of about 1 to 6. This, and the area of the footing will fix the depth.

Concrete is now frequently used for the entire foundation in place of brick and stone. The general form and size in this case may be the same as already described.

CHAPTER III.

CONDENSERS.

Object of a Condenser.—The expansion of steam in the cylinder of an engine causes its pressure to gradually fall until it finally reaches a point where it cannot be profitably used for driving the piston. At this stage some means must be provided for disposing of the vapor, in order to prevent back pressure during the return stroke of the piston. If the atmosphere did not exert a pressure of its own, the steam could be disposed of at once by exhausting into the open air. But there is in reality a pressure of nearly 15 pounds per square inch due to the weight of the atmosphere, from which it follows that the steam from a non-condensing engine cannot be expanded below this pressure to any advantage, as it must eventually be exhausted against atmospheric pressure on the return stroke.

If by any means this back pressure can be removed it is evident that the engine will not only be aided by relieving the resistance upon the exhaust side of the piston, but the steam can be expanded in the cylinder quite, or nearly, to absolute zero pressure, and thus its full expansive power be utilized.

If the steam is discharged into a closed chamber in such a manner that it comes in contact with a spray of cold water or with a series of tubes through which cold water is circulated, it will be deprived of nearly all of its latent heat and will condense. In either case the act of condensation is practically instanteous. As the water of condensation has only about 1/1600 of its original volume, it follows that the remainder of the space is void and that no pressure exists. If the expanded steam from an engine is conducted into this empty space, it will meet with no resistance and the limit of its usefulness will be reached. An arrangement of this kind in practical form is called a *condenser*. The cold water that produces the condensation is the *injection* water, and the heated water on leaving the condenser is called the *discharge* water.

Measurement of Vacuum.—The state of vacuum in a condenser is usually expressed in inches of mercury. For example, if the chamber of a condenser be connected by a rubber tube with the space above the mercury in a barometer, and the mercury column should fall to 26 inches, the condenser would be said to have 26 inches of vacuum. If the barometer stood at 30 inches before the rubber tube was attached, that is, when the space above the mercury was a vacuum, it would indicate that there was a pressure in the condenser equal to $30 - 26 = 4$ inches of mercury, or $4 \times .49 = 1.96$ pounds per square inch, which corresponds to a temperature of about 126°, and if the condenser were absolutely air-tight, would indicate that the water and vapor within were at that temperature. In order that the air may not accumulate in the condenser and destroy the vacuum, it is withdrawn, together with the heated water, by means of a pump.

Injection Water.

Weight of Injection Water.—The quantity of water required to completely condense the steam from an engine depends on two conditions: the pressure and weight of steam and the temperature of the injection water. With 26 inches of vacuum and injection water not above 70°, the required amount of injection water will be approximately from twenty to thirty times that fed into the boilers. If the temperature of the injection water is lower, a less quantity is required, and if higher, the amount must be increased; for example, at 80°, thirty-five times, and at 90°, fifty-two times the amount of feedwater is required. The exact amount in each special case can be computed, theoretically, by the following formula:

$$Q = \frac{S - (D - 32)}{D - I}$$

in which

Q = weight of injection water per pound of feedwater.

S = total heat of steam above 32° at exhaust or terminal pressure.

I = temperature of injection water.

D = temperature of discharge water.

The use of the formula will be made clear by applying it to a practical example:

Example.—A 100 horse power engine, requiring 20 lb. of steam per horse power, has a terminal pressure of 10 lb. absolute. The temperature of the injection water is 70° and we will assume a temperature of 120° for the discharge water, which corresponds approximately to 26 in. of vacuum. What will be the weight of injection water required?

From the above conditions we have

$$S = 1{,}140.9$$
$$I = 70$$
$$D = 120$$

Substituting in the formula, we have

$$Q = \frac{1{,}140.9 - (120 - 32)}{120 - 70} = 21 +$$

The weight of steam required to supply the engine is $100 \times 20 = 2{,}000$ lb. per hour. Therefore, the weight of injection water is

$$2{,}000 \times 21 = 42{,}000 \text{ lb.}$$

The reason for the above formula is evident. One pound of steam at 10 lb. pressure contains 1,140.9 B. T. U. above a temperature of 32°. That is, if the steam were condensed and cooled to 32°, 1,140.9 B. T. U. would be given off. But in the example it is only cooled to 120°. One B. T. U. will raise the temperature of 1 lb. of water 1°, or, in other words, 1 B. T. U. will remain in the condensed steam for each degree that its final temperature is above 32°.

Therefore, the heat given out by condensing 1 lb. of steam at 10 lb. pressure and cooling it to 120° is $1{,}140.9 - (120 - 32) = 1{,}052.9$ B. T. U. The heat absorbed by 1 lb. of water in raising it from a temperature of 70° to 120° is $120 - 70 = 50$ B. T. U.

Therefore, $1{,}052.9 \div 50 = 21 +$, the pounds of water which will be required to absorb the heat given off by the condensation and cooling of 1 lb. of steam under the conditions stated in the example. The matter of subtracting 32 from the temperature

D affects the result but little and is often omitted in practice, the formula being written.

$$Q = \frac{S - D}{D - I}$$

but for purposes of demonstration it is necessary to include it. Table X. will be found useful for determining the terminal pressure under different conditions.

TABLE X.

TERMINAL PRESSURES IN STEAM ENGINE CYLINDERS.

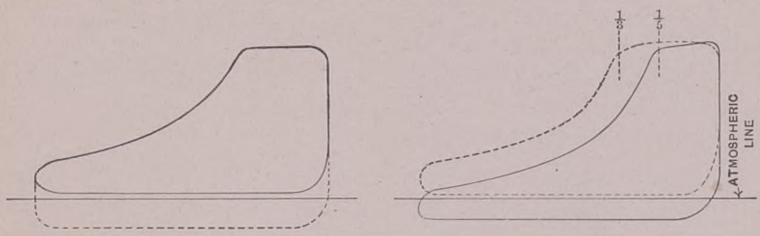
Clearance	0	1.75%	3%	5%	7%	9%
Cut-off						
$\frac{1}{10}$	0.1	0.115	0.126	0.143	0.159	0.174
$\frac{1}{6}$	0.167	0.101	0.191	0.206	0.221	0.235
$\frac{1}{4}$	0.25	0.263	0.272	0.286	0.299	0.312
$\frac{1}{3}$	0.333	0.344	0.353	0.365	0.377	0.388
$\frac{2}{5}$	0.4	0.410	0.417	0.428	0.439	0.449
$\frac{1}{2}$	0.5	0.509	0.514	0.524	0.533	0.541
$\frac{3}{4}$	0.75	0.754	0.755	0.762	0.766	0.771
$\frac{9}{10}$	0.9	0.902	0.903	0.905	0.906	0.908

To find the (theoretical) absolute terminal pressure, multiply the absolute initial pressure by the number opposite the given cut-off and in the column corresponding to the percentage of clearance.

Advantages of Running Condensing.

The advantages gained by using a condenser are an increase in the horse power of an engine and also a greater economy in the use of fuel per horse power developed. The power exerted by a steam engine during a single stroke of the piston is due directly to the difference between the pressures acting on the opposite sides of the piston. A vacuum does not in itself give power, but it removes the resistance from the exhaust side of the piston, and therefore adds just so much to the steam side.

Gain in Power by Condensing.—The value of a vacuum of 26 inches of mercury to an engine, making due allowance for the cost of production, may be approximated by considering it equivalent to a net gain of about 12 pounds average pressure per square inch of piston area. This is shown graphically in Fig. 20, in which the full line represents the indicator card when exhausting into the atmosphere. If the exhaust be connected with a condenser and the points of cut-off and release remain the same, the back-pressure line will drop to the position shown by the dotted line, and the difference between the two back-pressure lines will be added directly to the mean effective pressure, because it is a constant effective pressure extending throughout the entire stroke. From this it is evident that the power gained bears practically the same ratio to the power developed by the engine when non-condensing, as 12 pounds does to the mean effective pressure when running under the same conditions. So if the mean effective pressure of a non-condensing engine is known, a close approximation of the gain in power that will be derived by the use of a vacuum is easily determined.



Figs. 20 and 21. Showing Gain from Condensing.

The formula for computing the indicated horse power of an engine is

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

in which

P = mean effective pressure in pounds per square inch acting on the piston (M. E. P.).

L = length of stroke in feet.

A = area of piston in square inches.

N = number of single strokes per minute.

By substituting 12 for P in this formula, it will give the horse power gained by a vacuum of 26 inches when applied to a non-condensing engine.

Example.—An 18″ × 36″ non-condensing engine runs at a speed of 200 revolutions per minute and cuts off at ¼ stroke; boiler pressure 95 lb. gauge. What gain in horse power will be obtained by running condensing with a vacuum of 26 in., and what will be the final horse power?

Referring to Table I., Chapter I., and neglecting clearance, we have, M. E. P. $= [(95 + 15) \times 0.60] - 17 = 49$, and the I. H. P. when non-condensing is

$$\frac{49 \times 3 \times 254 \times 400}{33{,}000} = 452$$

When running condensing the I. H. P. is found in the same way by taking a back pressure of 3 lb. instead of 17, and we have

$$\text{I. H. P.} = \frac{63 \times 3 \times 254 \times 400}{33{,}000} = 582$$

as the final H. P. with a gain of $582 - 452 = 130$ H. P.

The gain in power could also have been found approximately by substituting 12 for 49 in the first equation.

Gain in Economy by Condensing.—The desirability of installing a condenser in any particular case will depend upon various conditions, among which are the size and water rate of the engine, cost of injection water, cost of fuel, and also to what extent the exhaust steam can be used for heating purposes.

The saving in fuel by the use of a condenser, when the power remains the same, is illustrated in Fig. 21. These two diagrams were taken from the same engine. The first, shown by the dotted lines, was obtained when running non-condensing, and the second when running condensing. The areas of the two cards are equal, so that the work done per stroke is the same in each case.

The cut-off, however, occurs at approximately ⅓ stroke in the first and ⅕ in the second, so that theoretically, the difference between ⅓ and ⅕ of a cylinder of steam is saved at each stroke. Actually it will be somewhat less than this, as the cylinder condensation will increase with the ratio of expansion.

Under favorable conditions in actual practice, it is customary to expect a saving in fuel of about 28 to 30 per cent in the case of simple engines, and 20 to 22 per cent for compound engines by running condensing. In the case of office buildings, where the greater part, if not all, of the exhaust steam can be used during the winter months for heating, and where the injection water must be purchased at city rates, there is nothing to be gained by condensing, and in many cases it would probably result in a loss. On the other hand, in manufacturing plants where water for condensing purposes can be had free of charge, or in large electric power plants where the exhaust steam is wasted, condensers are very generally employed.

Example.—Taking the same engine as in the previous example, what percentage of saving could be made by using a condenser and shortening the cut-off to keep the power the same?

The first step is to find the new point of cut-off which will be required to maintain the same power of the engine. This may be obtained algebraically by the formula already given for the M. E. P.

In this case the initial and mean effective pressures remain the same, the only change being in the back pressure, so that we may write

$$[(95+15)\times R]-3=49,$$

and solve for the ratio R, which gives us

$$(110\ R)-3=49,$$

or

$$R=\frac{49+3}{110}=0.47$$

Looking in Table I., we find that the nearest ratio, 0.46, corresponds to a cut-off of 1/6, which we may take in this case.

The saving in steam per stroke will then be

$$\tfrac{1}{4}-\tfrac{1}{6}\div\tfrac{1}{4}=\frac{0.25-0.166}{0.25}=33\%.$$

This may be carried still further by assuming the water rate of the engine when running non-condensing to be 30 lb. per H. P. per hour, and the efficiency of the boiler to be such that 9 lb. of water are evaporated per pound of coal. In this case the weight of steam required will be $452\times 30=13{,}560$ lb. per hour, and the weight of coal will be $13{,}560\div 9=1{,}506$ lb. per hour. We have already found the saving in steam to be 33 per cent, and as the saving of coal is in direct proportion, we shall have a saving of $1{,}506 \times .33 = 497$ lb. of coal per hour.

These figures are somewhat higher than would be obtained in practice, owing to leaks, increased condensation, and other losses, but the methods of computation are the same.

Comparative Economy when Running Condensing and Non-Condensing.

In making a comparison of the economy of running condensing and non-condensing in any particular case, it is necessary to compute the annual fuel cost, so called, the same as in making a comparison between simple and compound engines.

Items to be Considered.—The items composing this in the case of a condensing plant are as follows:

Fuel for power.

Fuel for heating.

Cost of injection water.

Interest and depreciation on first cost of engine and condensing apparatus.

For a non-condensing plant they are:

Fuel for power.

Fuel for partial heating in case the exhaust steam is not sufficient for this purpose.

Interest and depreciation on first cost of engine.

Interest and depreciation on first cost of additional boiler power, if found to be necessary.

A practical example involving some of the more important items noted above will serve as a guide in making computations of this kind.

Example.—Assume the case of a factory which is to be supplied with power from an 18″ × 42″ non-condensing engine running at 150 revolutions, cutting off at ¼ stroke and having a clearance of 9 per cent; the boiler pressure being 95 lb. gauge. The question is, which will be the more economical: to impose 5 lb. back pressure on the engine and use the exhaust steam in the heating system or to install a condenser and heat the building with live steam from the boilers? Suppose the water rate of the engine non-condensing to be 30 lb. per horse power per hour, the rate of evaporation of the boilers 9 lb. of steam per pound of coal, the cost of coal \$3 per ton, and condensing water to be available from a river free of cost, the only expense being that necessary to pump it from the river to the condenser; further, assume the distance and height to be such that it requires an expenditure of 500 foot pounds of work per gallon to accomplish this, and that steam is required six months in the year to supply 24,000 sq. ft. of direct radiation. The cost of installing pumps, condenser, and pipe line may be taken as \$3,000.

Case of Heating with Exhaust Steam.—From Table I. the ratio, *R,* for ¼ cut-off and 9 per cent clearance is 0.646, and assuming a back pressure of 5 lb. gauge, the mean effective pressure will be $[(95+15)\times 0.646]-20=51$ lb., making the indicated horse power of the engine

$$\frac{\overset{P}{51}\times\overset{L}{3.5}\times\overset{A}{254}\times\overset{N}{300}}{33{,}000}=412 \text{ I. H. P.}$$

The weight of steam required will be $412\times 30=12{,}360$ lb. per hour, and the weight of coal, $12{,}360\div 9=1373$ lb., so that the cost of coal at \$3 a ton will be

$$\frac{1{,}373\times 3}{2{,}000}=\$2.05 \text{ per hour.}$$

For an engine of this type and cut-off, a cylinder condensation of about 20 per cent may be assumed, which will leave $12{,}360\times 0.80=9{,}888$ lb. of steam per hour for heating purposes. Part of this can be used for heating the feed water. The temperature of steam at 5 lb. gauge pressure is 228°, and its latent heat is 954 heat units.

If the feed water is to be heated from 70° to 210°, it will require $(210-70)\times 12{,}360=1{,}730{,}400$ heat units per hour; or will condense $1{,}730{,}400\div 954=1{,}814$ lb. of steam. This leaves $9{,}888-1{,}814=8{,}074$ lb. of steam for radiator service. One square foot of direct radiating surface will condense about

⅓ of a pound of steam per hour, therefore 24,000 sq. ft. will condense $24{,}000 \times \frac{1}{3} = 8{,}000$ lb. per hour, which leaves a surplus of 74 lb. of steam to be exhausted outboard. This makes the full expense $2.05 per hour for power and heat. As the surplus steam would be wasted during the summer, the fuel expense would be uniform throughout the year.

Saving Made by Condenser.—For comparison it is now necessary to find what the saving in fuel for power would be if a condenser were used. The first step is to find the required cut-off to give the same power as in the foregoing example with the reduced back pressure. $[(95 + 15) \times R] - 3 = 51$, from which

$$110\,R - 3 = 51, \text{ or } R = \frac{51 + 3}{110} = 0.49$$

Looking in Table I. it is found that this ratio corresponds approximately to $\frac{1}{7}$ cut-off, which may be taken as the new point. The saving in steam per stroke will then be

$$(\tfrac{1}{4} - \tfrac{1}{7}) \div \tfrac{1}{4} = \frac{0.25 - 0.14}{0.25} = 0.44, \text{ or } 44\% \text{ roughly}$$

This makes the weight of coal per hour $1{,}373 \times 0.56 = 769$ lb., for power alone. To this must be added the amounts required for pumping the condensing water and for heating.

Power to Pump Injection Water.—The next step is to compute the quantity of condensing water in order to determine the power required for pumping. Interpolating in Table X. the terminal pressure ratio for $\frac{1}{7}$ cut-off and 9 per cent clearance is found to be approximately 0.22, which would give a terminal pressure of $(95 + 15) \times 0.22 = 24.2$ lb., absolute, and S the total heat of the exhaust steam at this pressure above 32°, is 1,154. For the heating season the average temperature of the injection water may be taken as 40°; the discharge water temperature may be taken as 110°. Substituting these values in the formula for injection or condensing water, we have

$$Q = \frac{1{,}154 - (110 - 32)}{110 - 40} = 15.2 \text{ lb.}$$

The saving in fuel and water by running condensing was shown to be 44 per cent, so that the weight of steam required by the engine when running condensing will be 12,360 × 0.56 = 6,922, and if 20 per cent of this is condensed in the cylinder it will leave 6,922 × 0.80 = 5,538 lb. to be liquefied by the condenser per hour. The quantity of injection water required per pound of steam condensed being 15.2 lb., there will be required 5,538 × 15.2 = 84,178 lb., or 84,178 ÷ 8.3 = 10,142 gallons of water per hour for condensing.

If 500 foot pounds of work are necessary for pumping each gallon of water from the river, it will require 500 × 10,142 = 5,071,000 foot pounds per hour, or 5,071,000 ÷ 60 = 84,517 foot pounds per minute for this purpose; the power used therefore will be 84,517 ÷ 33,000 = 2.6 horse power approximately. In the case of small direct-acting steam pumps, the weight of steam required is rarely less than 120 lb. per horse power, so if this type of pump is used, the weight of steam will be 2.6 × 120 = 312 lb. per hour, which will require 312 ÷ 9 = 35 lb. of coal.

Summary of Items.—It has been shown that 8,000 lb. of steam are required per hour for heating. This will require 8,000 ÷ 9 = 888 lb. of coal. Consequently, the total fuel required per hour when running condensing will be

Engine	769 pounds
Pump	35 pounds
Heating	888 pounds
	1,692 pounds

as against 1,373 when running non-condensing, during the heating season.

In order to make the comparison complete, the coal consumption for a year must be computed. Suppose the factory runs 10 hours per day for 300 days. When running non-condensing, the weight of coal required for the year would be 1,373 × 10 × 300 = 4,119,000 lb. In the second case there would be required 1,692 × 10 × 150 = 2,538,000 lb. during the six months which require heat, and (769 + 35) × 10 × 150 = 1,206,000 lb. for power alone during the other six months, making the yearly consumption, 3,744,000 lb. This shows a margin of 4,119,000 — 3,744,000 = 375,000 lb. in favor of the condensing plant. This would amount to $366{,}000 \div 2{,}000 \times 3 = \$562.50$ per year. Against this must be charged the interest and depreciation on the cost of the condensing plant which we will take as 12 per cent, or $3{,}000 \times 0.12 = \$360$, which leaves a balance of $562.50 - 360 = \$202.50$.

In the above comparison no account has been taken of the fact that the condensing water will be warmer in the summer, thus making the quantity of water, and therefore the quantity of coal required for pumping somewhat greater in the summer than in the winter. This correction can be easily made if desired. An advantage of the non-condensing system not taken into account is the fact that the feed water is heated up to a temperature of 210°, while in the latter case the condensed steam in the hot-well will range from about 115° to 125°.

This example serves to show in a measure the method of making the computations for a number of the more important conditions which are commonly met with in practice. The data furnished in any special case will vary from that given above, but it is a simple matter to make the necessary substitutions. If one wishes to go into the smaller details more accurately it is an easy matter to do so.

In case one of the so-called vacuum systems is used, it affects the computations only so far as the back pressure on the engine is concerned. The amount of vacuum which it is possible to maintain in the heating system will depend almost entirely upon the tightness of the joints and freedom from leaks of various kinds.

Types of Condensers.

Condensers are divided into two general classes, known as surface and jet condensers. In the former the exhaust steam enters a chamber filled with small tubes through which water is made to circulate, and condensation is brought about by the steam coming in contact with the colder surface of the pipes. The cooling water is forced through the pipes by means of a circulating pump, and an air pump, so called, is provided for removing the condensed steam and air from the vacuum chamber.

Jet and Surface Condensers.—In the jet condenser the steam and injection water mingle together in the condensing chamber,

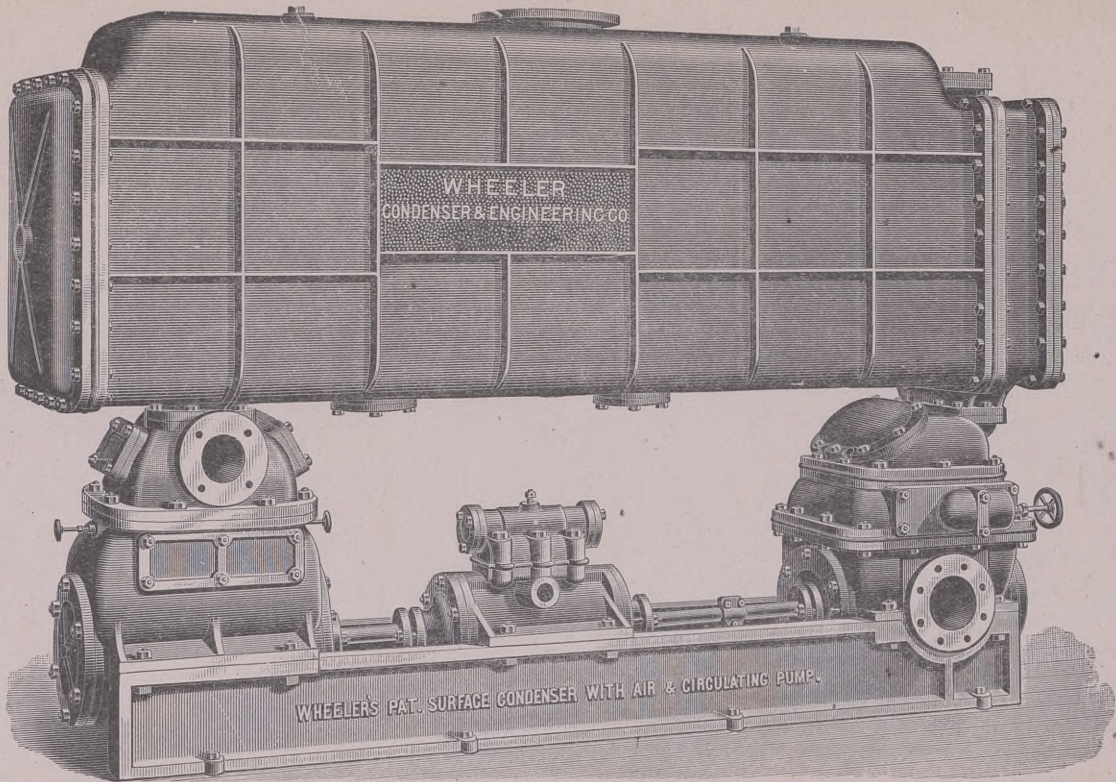


Fig. 22. Wheeler Surface Condenser.

and the condensed steam, air, and discharge water are removed by means of the same pump. The surface condenser is used almost exclusively for marine work, while both the surface and jet condensers are used on land. The surface condenser is heavier and more bulky than the jet condenser for any given capacity, but it may be used with any kind of water, which is not the case with the jet condenser if the discharge water is to be fed into the boilers. The condensed steam from a surface condenser may be used again in the boilers, provided from 10 to 12 per cent of its weight of fresh water is added. Otherwise the effect of the dis-

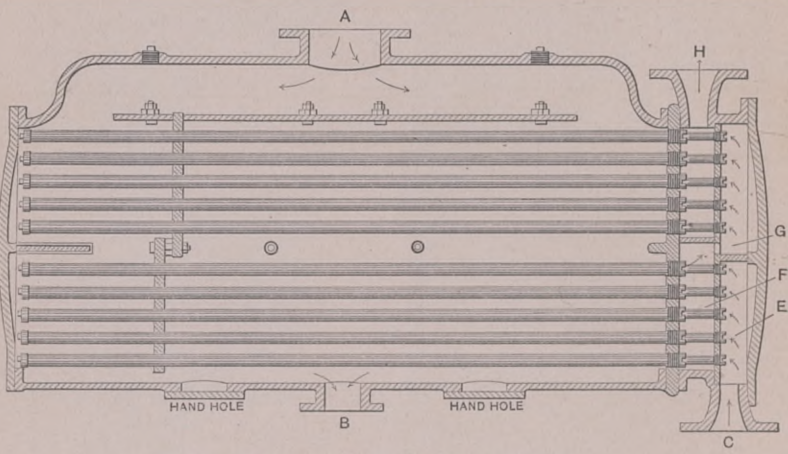


Fig. 23. Section of Wheeler Condenser.

tilled water is to corrode the boiler plates. The oil in the exhaust steam must be separated by means of an oil separator before it enters the condenser. This method is useful when the only available water supply contains solid matter, salts, or acids which would be injurious to the boilers. The same water is used over and over again, except for the dilution with fresh water as above stated, so that the steam circuit is practically a closed one.

The Wheeler Condenser, shown in Fig. 22, is a typical form of surface condenser. The condensing chamber in this case is made of cast iron and is supported above the pumps.

The water or circulating pump is shown at the right and the air pump at the left. The air, water, and steam pistons are attached to a common rod, with the steam cylinder at the center, as shown. The condensing chamber is shown in section in Fig. 23.

Exhaust steam enters at *A*, where it strikes a baffle plate which serves to distribute it over the cooling surface and also prevents its cutting the tubes nearest the inlet. The steam after being condensed passes with the air and non-condensable vapors to the air pump through the nozzle *B*. Space should be left below the lower tubes so that the water of condensation cannot come in contact with them and thus become chilled. The circulating or cooling water enters through the nozzle *C* into the chamber *E* and

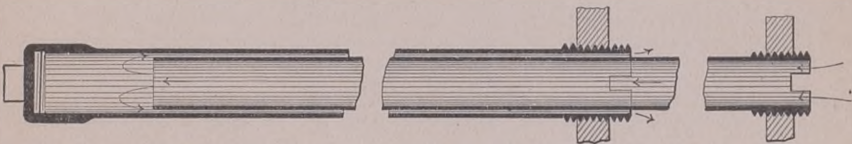


Fig. 24. Tube of Wheeler Condenser.

from here passes through the tubes into the chamber *F* and thence through openings into *G*, then through the upper group of tubes and is discharged through the outlet *H*. The peculiar construction of one of the tubes is shown in Fig. 24. This consists of an inner and an outer tube, the path of the water being as shown by the arrows. In another form the tubes are single, and the water passes through the lower group of tubes to a chamber at the left, and back again through the upper tubes to the outlet.

Area of Cooling Surface.—The required cooling surface of the tubes may be computed by the equation

$$S = \frac{WL}{180\,(T - t)}$$

in which

S = the required cooling surface in square feet for brass tubes.
W = weight of steam to be condensed per hour.
T = temperature of steam at condenser pressure.
t = the average temperature of the circulating water, which is approximately the arithmetical mean of the initial and final temperatures.
L = the latent heat of steam at temperature T.

Example.—What area of cooling surface is required in a condenser to be used with a 100 horse power engine using 25 lb. of steam per horse power per hour? Assume for ordinary conditions that the pressure in the condenser is 3 lb. absolute, and that the initial temperature of the circulating water is 70° in summer time, with a final temperature of 110°.

We have from the foregoing formula

$W = 100 \times 25 = 2{,}500$

$T = 141$

$t = \dfrac{70 + 110}{2} = 90$

$L = 1{,}015$

which, substituted in the formula, gives

$$S = \frac{2{,}500 \times 1{,}015}{180\,(141 - 90)} = 276$$

or, $276 \div 100 = 27$ sq. ft. of cooling surface per H. P.

The Condenser Tubes are usually of solid drawn brass and generally tinned outside and inside. They vary in diameter from ½ inch to 1 inch, but are more commonly ¾ inch outside diameter. Such tubes are about 0.048 inch in thickness; they are placed zigzag, and their pitch measured from center to center may be from 1.5 to 1.7 their diameter. The number of tubes which may be fitted into a square foot of plate is as follows:

TABLE XI.

NUMBER OF TUBES PER SQUARE FOOT OF PLATE.

Pitch of tubes, inches	Number per square foot
1	172
$1\frac{1}{16}$	150
$1\frac{1}{8}$	137
$1\frac{5}{32}$	128
$1\frac{3}{16}$	121
$1\frac{7}{32}$	116
$1\frac{1}{4}$	110
$1\frac{9}{32}$	106
$1\frac{5}{16}$	99

Table XII. gives the over-all dimensions of a few standard sizes of the Wheeler surface condenser. These, however, are made in many different sizes and with varying proportions to meet all conditions.

TABLE XII.

OVER-ALL DIMENSIONS OF WHEELER SURFACE CONDENSER.

Square feet condensing surface	Pump cylinders Size, inches	Length Ft. In.	Width Ft. In.	Height Ft. In.
150	5 and 7 by 6	6 2	1 9	4 0
200	5 " 7 " 6	6 9	1 9	4 0
300	6 " 7 " 8	6 8	2 1	6 0
600	7½ " 10 " 10	9 4	1 9	6 0
900	10 " 12 " 12	9 8	2 4	6 11
1200	10 " 12 " 14	9 9	2 5	7 4
1500	12 " 16 " 16	12 0	2 10	8 4
2000	12 " 16 " 16	12 0	3 2	8 8
2400	12 " 16 " 18	12 5	4 2	8 9

The Worthington Jet Condenser is shown in Fig. 25. As already stated, the injection water acting directly on the steam will produce a greater drop in pressure with less water than a surface condenser, and the bulk and weight of the condenser itself is also less. When the condensed steam is to be pumped back into the boilers, the injection water goes with it, so that in this case the water supply must be of a quality which is not injurious to the boiler plates.

Referring to Fig. 25, the action is as follows: The exhaust steam from the engine enters the condensing chamber at *A;* the injection water enters at *B; C* is the spray pipe and has at its lower extremity a number of vertical slits through which the water passes and becomes spread into thin sheets. The spray cone *D* breaks the water passing over it into a fine spray and thus causes a rapid and thorough mixture of the steam and water. The spray cone is adjusted to give the proper amount of water by means of a stem passing through the top of the condenser.

The injection water and condensed steam fall together through the opening *F* into the pump and are discharged either into a convenient sewer or into a hot-well when the discharge water is to be used for feeding the boilers. The condensing chamber is ordinarily made from ⅓ to ½ the volume of the engine cylinder with which it is to be used.

The injection water may be raised from a tank or other supply by the vacuum action of the condenser, provided the elevation is not more than 20 feet. If more than this, some form of pump must be used. The apparatus is put in operation by first starting the pump to produce a partial vacuum in the condensing chamber. This causes the injection water to enter through the pipe attached

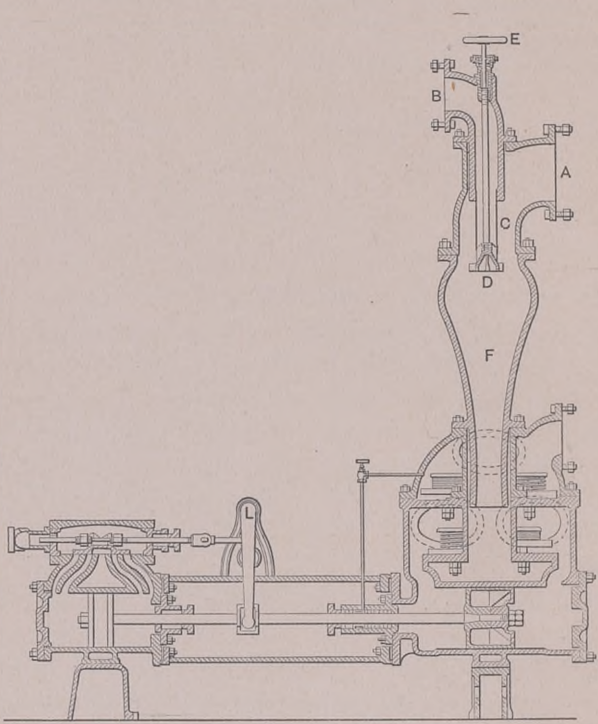


Fig. 25. Worthington Jet Condenser.

at *B*. The main engine may now be started, and as the exhaust enters through *A* it meets the spray of cool water and is rapidly condensed, thus maintaining a constant vacuum.

Table XIII. gives the approximate floor space required for several sizes of the Knowles jet condenser, based on 70° temperature of condensing water. For other temperatures, larger or smaller sizes must be selected as required.

TABLE XIII.

DIMENSIONS AND FLOOR AREA OF KNOWLES SIPHON CONDENSER.

Pounds of steam condensed per hour	Diameter of steam cylinder	Diameter of air cylinder	Stroke	Floor space Width	Floor space Length
	In.	In.	In.	Ft. In.	Ft. In.
1560	5½	8	7	2 5	4 0
2240	6	9	10	2 10	4 10
3340	6	10	12	3 4	5 7
4800	8	12	12	3 4	5 7
6400	8	14	12	3 10	6 0
6540	8	14	16	4 0	6 7
8540	10	16	16	4 6	7 0
10800	12	18	18	4 6	7 10
13340	12	20	24	5 11	9 8
16140	14	22	24	5 10	9 9

Knowles Siphon Condenser.—Another form, the Knowles "Spirojector" condenser, is shown in Fig. 26. By a special form of cone the injection water is made to take a spiral or rotary motion in its downward flow; this produces a stronger downward suction and is more effectual in drawing the air and vapor through the narrow or middle part of the condenser.

The exhaust steam entering at the top of the condenser passes through the center of the cone and meets the rapidly descending spiral current of water and is immediately condensed.

The water column or discharge pipe between the condenser and the hot-well should be long enough to overcome atmospheric pressure in order to carry the air down into the hot-well after it is drawn through the neck of the condenser.

The supply of injection water can be drawn from a tank or other supply after a vacuum is formed in the condenser, provided the distance above the hot well is over 10 feet. If the head of water is less than 10 feet, it is necessary to use a pump. A centrifugal or rotary pump is commonly used if the water flows to the pump by gravity, but if it is necessary to raise it to the pump from a lower level, a steam or power pump should be used. There are other forms of condensers made, embodying the same principles, but those shown are the more common, and serve to illustrate the general construction and operation of this piece of apparatus.

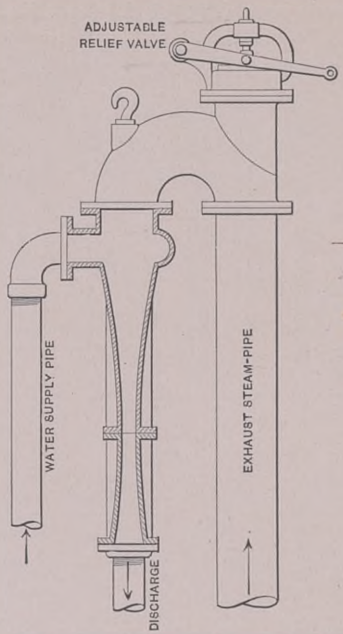


Fig. 26. Knowles Siphon Condenser.

Cooling Towers.

We have seen from previous computations that from 20 to 30 per cent may be saved in the cost of fuel by the use of a condenser when the injection water can be had free of charge. This, of course, is practically impossible in large towns and cities, unless the plant happens to be located near a river or lake from which the water can be taken. In order to avoid the expense of injection water and still retain the advantages to be derived from a condenser, various methods have been devised, by means of which the discharge water may be cooled and used over and over again. The most common of these is the *cooling tower,* several forms of which are in common use. The general principles involved are practically the same in each, and are very simple.

Principle of the Cooling Tower.—The discharge water as it leaves the condenser is pumped to the top of the tower, where it is distributed upon a series of extended cooling surfaces over which it trickles in thin sheets to the bottom and is collected in a reservoir. From here it is taken by a circulating pump and again forced through the condenser. A current of air is made to flow

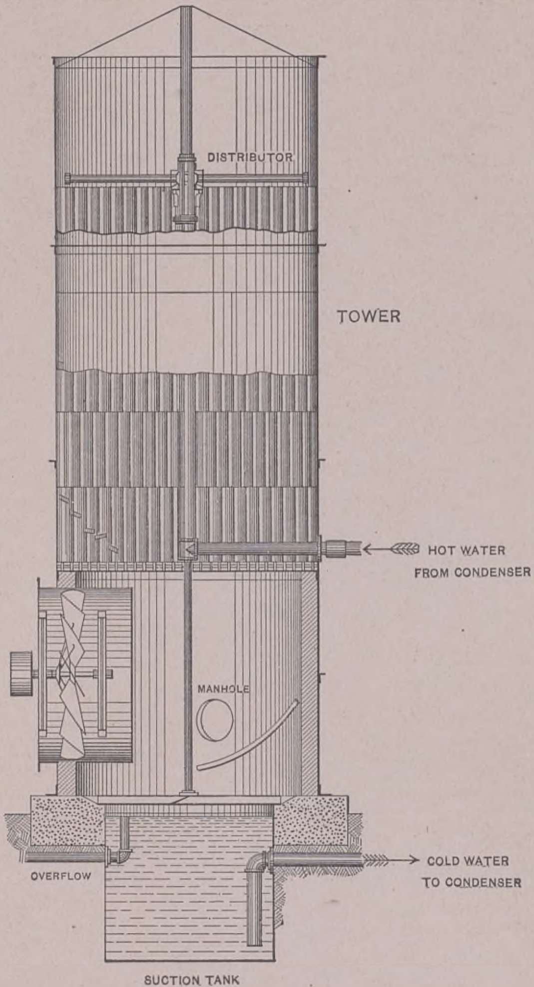


Fig. 27. Worthington Cooling Tower.

over the cooling surfaces, either by the use of a fan or by the chimney effect of the enclosing shell of the tower.

The cooling effect of an apparatus of this kind depends upon three causes. First, radiation from the pipes and sides of the tower; second, the contact of cool air with the heated water; and third, evaporation. The last is by far the most important, as the evaporation of a pound of water carries away over a thousand B. T. U.

With the best forms of cooling towers the temperature of the circulating water may easily be reduced 40° to 50° with a loss from evaporation not exceeding 3 or 4 per cent of the total quantity of water passing through the tower.

The Worthington Tower.—The general form of a cooling tower with forced air circulation is well illustrated by the Worthington tower shown in Fig. 27. The cooling surface in this case is made up of pieces of 6-inch terra-cotta pipe in 2-foot lengths, placed on end in rows as shown. A steel shell encases the whole, and air is supplied by a disk fan near the bottom. The water to be cooled is pumped to the top of the tower, where it is discharged through a special distributing device and evenly spread over the upper course of the evaporating surface; from here it falls slowly over the successive courses to the cold-water tank at the bottom.

Natural-draft cooling towers are similiar in construction except the fan is omitted and the top of the shell is extended in the form of a flue for a considerable distance above the cooling surface.

The tower may be placed just outside the boiler house or upon the roof of the building, as most convenient.

CHAPTER IV.

STEAM AND FEED PIPING.

The design of a system of piping for a high-pressure steam plant is a matter of much importance, and should be carefully worked out in detail before any of the apparatus is installed. The boilers and engines and their auxiliaries should first be located on the drawings in their true positions, and then connected in a manner best suited to the existing conditions.

Piping Plans.—The plans for medium sized plants are usually laid out to a scale of ⅜ or ½ inch to the foot, and all valves and fittings drawn in their true proportion to make sure that there is sufficient space for the work to be made up. The principal points to be kept in mind when laying out a system of this kind are as follows: Pipes of sufficient size to prevent loss of pressure; reasonable compactness, to avoid excessive condensation; provision for expansion; freedom from pockets for the collection of water; and a system of drainage which shall keep the pipes free from condensation under all conditions.

General Arrangement.

In electric power plants of medium size, the arrangement of boilers and engines is much the same and usually follows one of two general schemes. In one case the boiler and engine rooms are placed end to end, with boilers and engines lying in the same direction, as shown in Fig. 28; while in the other arrangement they are placed back to back, with a wall between as indicated in Figs. 29 and 30. When the plant is located in the basement of an office building, or forms part of the power and heating system of some public building or institution, these arrangements cannot usually be carried out in full, and various modifications are necessary in each particular case. However, these diagrams will be found useful in many instances, even though the conditions are quite different, and will serve as a basis in laying out work of this kind.

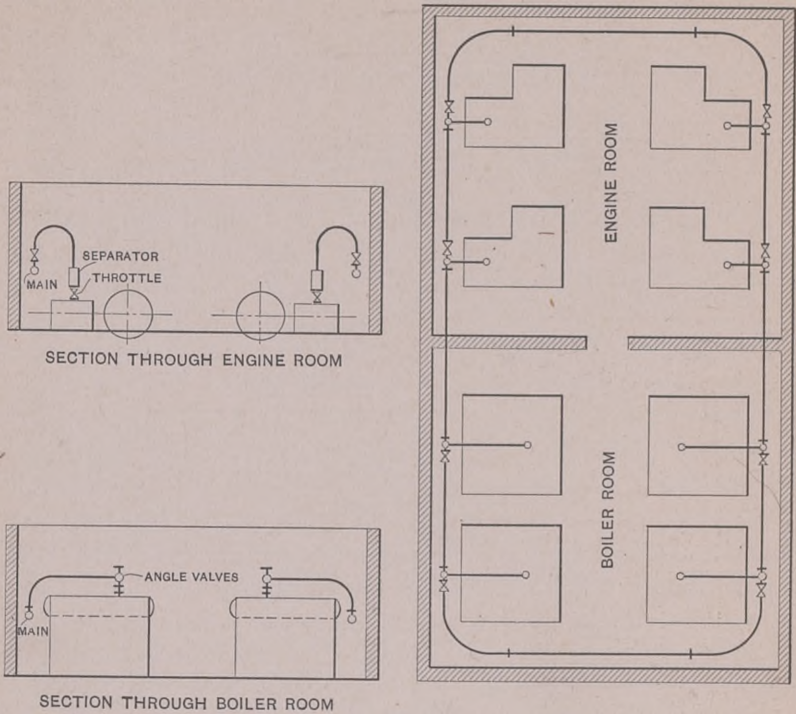


Fig. 28. Power Plant with Boiler and Engine Rooms Placed End to End.

High-Pressure Piping.

Ring System of Piping.—The system of piping shown in Fig. 28 is known as the "ring" system. In this arrangement the steam passes from the boilers to the engines by two paths, and any section of the main may be cut out by closing two of the valves. The main, in this case, must be made full size for its entire length and the cut-out valves are necessarily of the same size, which adds considerably to the first cost. On the other hand, it practically serves the purpose of a duplicate system of piping, and in case of a leak or accident, the damaged section can be cut out by sacrificing a single engine or boiler, according to its location. Another arrangement of the ring system is shown in Fig. 29

where the boilers and engines are placed in much the same manner as in the back to back arrangement in Fig. 30.

Back to Back Arrangement.—In the back to back method the main or header is commonly carried on brackets secured to the boiler room wall. In this arrangement each boiler and engine has its valved connection with the header, which is common to all. In small plants this is usually made in one section, but where it is desired to guard against accidents so far as possible, it may be divided into sections as shown in Fig. 30. In this case only one boiler and engine will be thrown out of use by a break in the

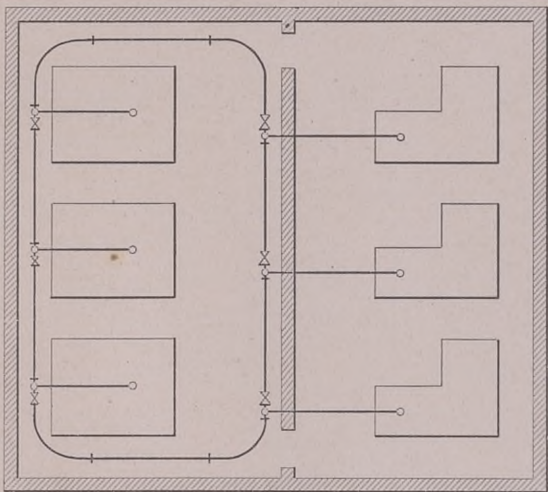


Fig. 29. Power Plant with Boiler and Engine Rooms Placed Back to Back.

main, provided those connected with each section are properly proportioned. The main may be placed overhead as shown in Figs. 28 and 30 or supported upon piers or brackets at the rear of the boiler settings.

The latter arrangement is commonly used in large plants where the engine room floor can be placed at a higher level than that of the boiler room. This allows the connections to be carried beneath the floor and does away with heavy exposed piping in the engine room. In this way the room can be kept cooler, and in case of leaks or breaks the escaping steam does not reach the electrical apparatus so readily. Although having these advantages, it cannot usually be employed in office buildings and similar locations on account of the limited space.

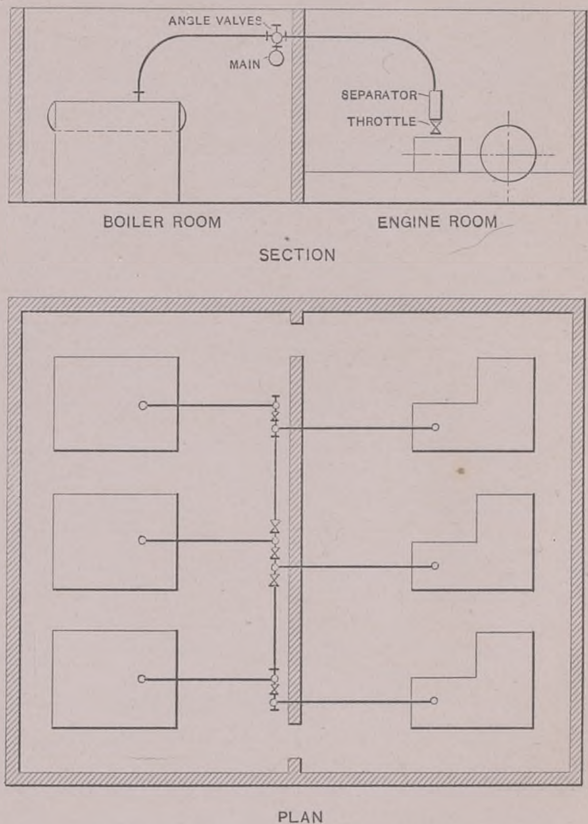


Fig. 30. Power Plant with Arrangement Similar to Fig. 29, but with Different Piping Plan.

In making provision for expansion it is customary to use pipe bends and swivels so far as possible, in preference to slip joints.

Connections to the Boilers.—Common methods of connecting boilers with the main are shown in Figs. 28 and 30. In the first case an angle valve is placed directly upon the boiler nozzle, and the lead drops into the top of the main by means of a sweep bend. If head room is limited an elbow may be substituted for the angle valve, and a gate valve placed just beyond it, with the stem in a horizontal position. Some engineers place two valves in the lead, as a precaution against leakage of steam from the main into the boiler while the latter is shut down for inspection or repairs.

Connections to the Engine should always be taken from the top of the main, and if suitably located a full U bend may be used as shown in Fig. 28, with a gate valve in the pipe near the main, in addition to the throttle at the engine.

When there is sufficient head room the pipe bend is often connected directly to the boiler nozzle as shown in Fig. 30 and connection made with the top of the main either by means of an angle valve or an elbow and gate, the latter being placed in the horizontal portion of the pipe near the main.

The illustrations given show only a few of the methods in common use, and may be varied or combined in different cases to meet the requirements.

Cast-Iron Fittings.—In small plants, where moderate pressures are carried, cast iron fittings may often be used in place of pipe bends, provided special care is taken to use swivel joints wherever possible. Rigid connections should be avoided in every case, and the engineer must always have in mind the flexibility of the piping under expansion and contraction.

Steam Separators are commonly placed close to the throttle of the engine. They not only serve to remove the moisture, but when of large size they provide a reservoir of steam close to the cylinder which insures a higher and more uniform pressure up to the point of cut-off, and also lessens the vibration in the steam pipe caused by the intermittent flow of steam to the cylinder.

Exhaust Piping.

The exhaust piping will vary considerably in different cases, depending upon whether the plant is to be run condensing or non-condensing, and also upon the disposal of the exhaust steam in non-condensing plants. When there is a sub-basement under

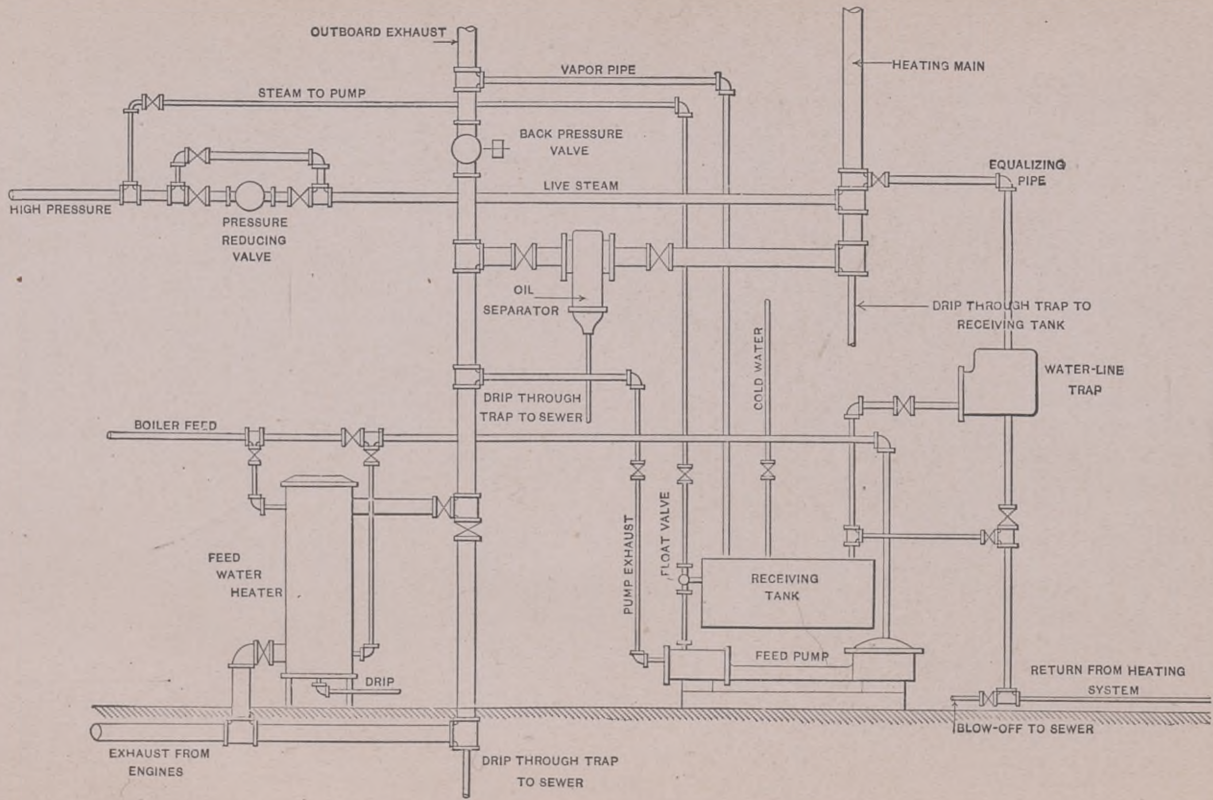


Fig. 31. Layout of Piping for Non-condensing Plant.

the engine room, the exhaust piping may be carried in this space, together with the steam connections, otherwise they are run in covered trenches below the floor. The general method of making the exhaust connections under different conditions can best be illustrated by a few diagrams.

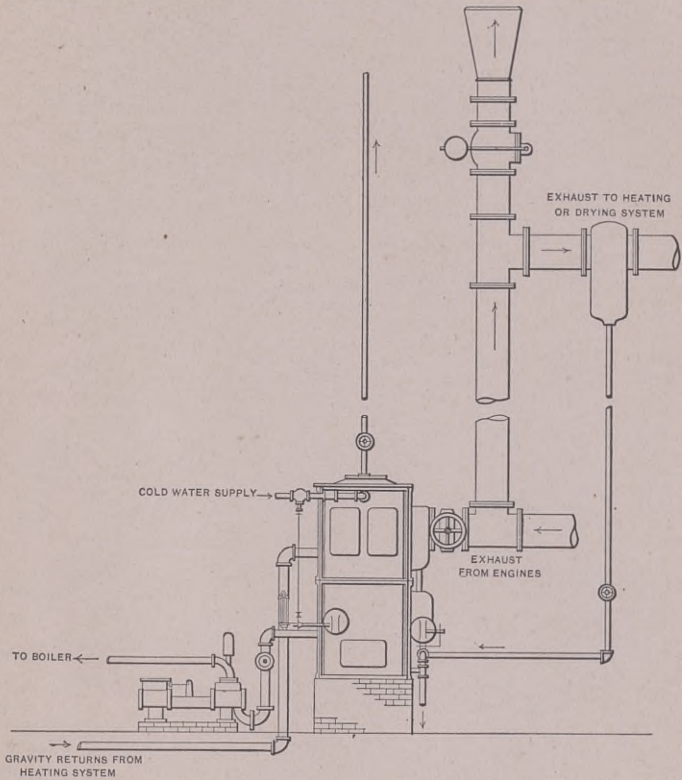


Fig. 32. Connections to Feed-water Heater.

Exhaust Piping for Non-Condensing Plant.—Fig. 31 shows the method of connecting up a non-condensing plant in which the exhaust steam is used for heating purposes.

The exhaust main from the engines is carried beneath the floor and is so valved that the steam can be passed either outboard through a back-pressure valve, or into the heating system through a grease extractor. A closed feed-water heater is connected with the main so that either a part or the whole of the exhaust can be made to flow through it. This arrangement allows the heater to be cut out in case of repairs and also makes it possible to pass all of the exhaust through it in the summer time when the heating system is not in use, if so desired.

A cross connection is made with the high-pressure main for automatically supplying live steam to the heating system through a reducing valve in case the exhaust should prove insufficient at any time. The returns from the heating system are trapped into a vented receiver and pumped back to the boilers automatically when the waterline in the tank rises above a given point.

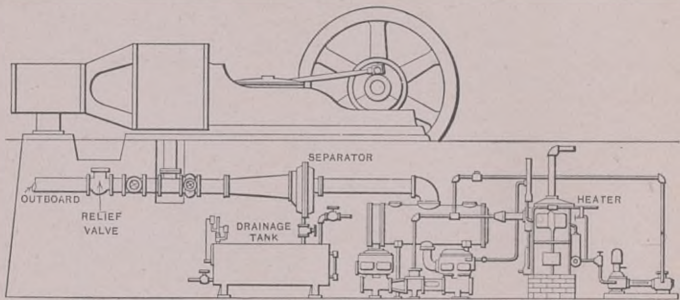


Fig. 33. **Condenser Connections.**

Connections to Feed-Water Heater.—Sometimes the feed-water heater has only a single steam connection as shown in Fig. 32. In this arrangement, which is sometimes called the "induction system," there is no circulation of steam through the heater, only enough being drawn in to take the place of that which is condensed. This condition makes it necessary to provide a vent for the gases which are liberated from the steam, otherwise the heater would become air-bound.

The best method of venting is to provide a small pipe from the top of the heater to the atmosphere, carrying this pipe 8 or

10 feet higher than the top of the exhaust. A valve should be placed in the vent pipe near heater for regulating the area of outlet.

When the heater is installed on the induction system it is necessary to place an independent grease extractor in the branch leading to the heating system as shown. The separator may be trapped to waste through the water-seal on the heater.

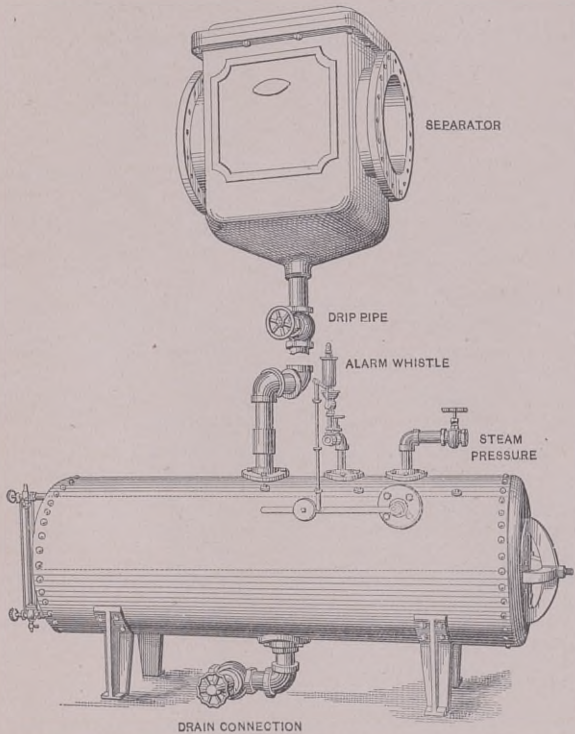


Fig. 34. Drip Tank and Separator.

This is a good method of connecting an open heater with an exhaust heating system, as it does away with any possibility of spray being carried over from the open pans or trays into the radiators, which might occur if the steam was passed through at too high a velocity.

Connections to Surface Condenser.—Fig. 33 shows the method of connecting a surface condenser when the discharge water is to be returned to the boilers. The piping is so arranged that the exhaust can be turned either outboard or passed into the condenser through an oil separator as desired. A relief valve is placed in the branch leading outboard which opens automatically in case anything happens to the condenser. The exhaust from the air and feed pumps should be turned into a heater.

It is evident that when in operation a partial vacuum exists in the separator as well as in the condenser, hence the drip cannot

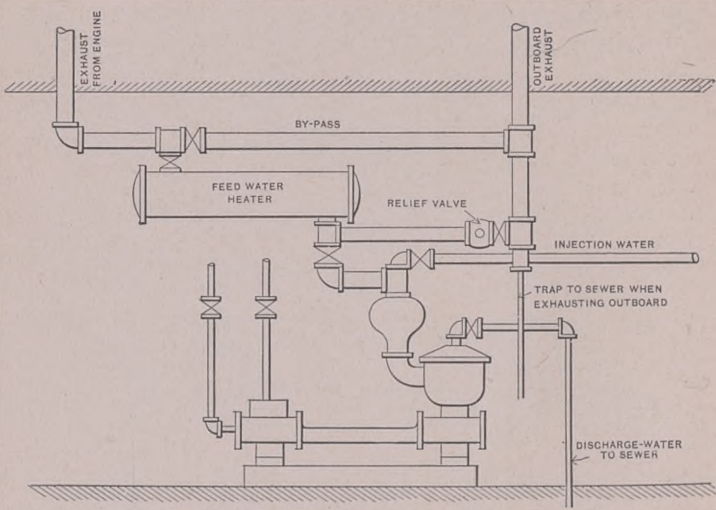


Fig. 35. Connections to Jet Condenser.

discharge against atmospheric pressure, and for this reason special provision must be made for drainage. One method of doing this is to lead the drip to a closed tank of good size with connections as shown in Fig. 34. This tank has a float valve connected with a small steam whistle. When it becomes nearly filled with oil and water the alarm is given and the tank can be emptied by closing the drip pipe, opening the drain and admitting steam pressure to the top of the tank.

Another method which operates automatically is to use a good form of return trap in place of the tank. In this case, steam at a very low pressure should be connected with the trap for discharging its contents.

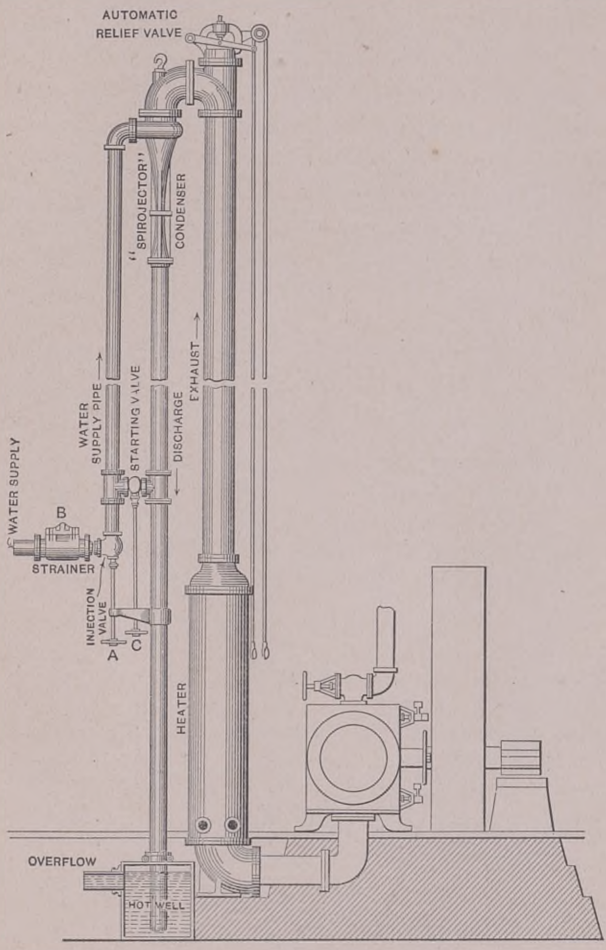


Fig. 36. Connections to Siphon Condenser.

Connections to Jet Condenser.—Fig. 35 illustrates the connections for a jet condenser where the discharge water is turned into the sewer. In this case no oil separator is required, and a primary feed-water heater is substituted in its place. There is a connection outboard through a relief valve as before. The exhaust from the pumps should be discharged into a secondary heater through which the boiler feed should be made to pass after leaving the primary heater as already described in connection with feed-water heaters in a previous chapter. The arrangement is such in this case that all condensation from the heater is carried into the condenser with the flow of steam, so that no special drips are required.

Connecting to Siphon Condenser.—Fig. 36 shows the method of making the connections for a siphon condenser of the Knowles type. The condensing water may be taken from a tank or flume as shown, or may be supplied by a pump placed in the boiler or engine room.

Location of Condenser.—If it is not convenient to place the condenser at a lower level than the engine it may stand on the same grade; the only advantage in the arrangements shown being that of drainage.

In some plants each engine is provided with its own condenser, while in others, two or more are connected with the same one; in the latter case each engine should have a valve in the exhaust pipe near the cylinder.

Drainage.

Of equal importance with flexibility is the matter of drainage.

Steam pipes should always be graded, if possible, so that the flow of steam and water will be in the same direction; if this cannot well be done the pipes should be made extra large. Pockets are to be avoided, but if for any reason they are found to be necessary in special cases, they should be effectively drained at the point where the pipe rises again.

Drips from Steam Mains.—When mains of considerable size are carried for long distances, they should be dripped at intervals of 125 to 150 feet into a line running back to the boiler room; and in case the main header is divided into sections, each should have its separate drip.

Location of Valves.—Globe valves ought never to be used in horizontal pipes with the stem in a vertical position, as a pocket will be formed for holding back the water of condensation; neither should a valve of any kind be used in a vertical pipe where it will form a pocket for the accumulation of water above it. This applies especially to vertical pipes above the nozzles of boilers.

Gate valves are better adapted for use in horizontal pipes under nearly all conditions, but care should be taken not to place them with the stem vertical and the hand-wheel at the bottom, lest they be left partially closed, and thus make an obstruction at the bottom of the pipe. When the throttle valve of an engine or pump is placed at the bottom of a vertical supply pipe, the pocket which is formed should be dripped by means of a "bleeder" connected into the pipe just above the valve. This may be blown out by hand just before starting up, or the drip may be connected with a trap which will keep the pipes clear automatically. The last arrangement is always necessary in the case of elevator pumps which run intermittently and are started automatically by a drop of pressure in the pressure tank.

Return of Condensation.—The condensation from piping containing live steam is usually collected and returned to the boilers by means of a pump or return trap. When the points to be dripped are under different pressures an automatic return pump with a vented receiver should be used, and each drip line provided with a trap discharging into it. If the drips are all under practically the same pressure and located near together, the condensation may be returned directly to the boilers by means of the "steam loop" or "Holly System," or they may be connected with the receiver of a return pump without the use of traps. If this is done, the different drip lines should be brought together below the water line of the tank and provided with check valves. This also applies to the use of a return trap.

Drips from Exhaust System.—The drips from oil separators, feed-water heaters, and all other parts of the exhaust system containing oil are usually trapped to the sewer. Cylinder cocks are commonly connected with the blow-off tank, which allows the steam to pass off through the vapor pipe.

Feed Piping.

This is usually of brass in first-class plants, although extra heavy iron pipe is sometimes used. Long-turn fittings and gate valves are to be preferred in this class of work.

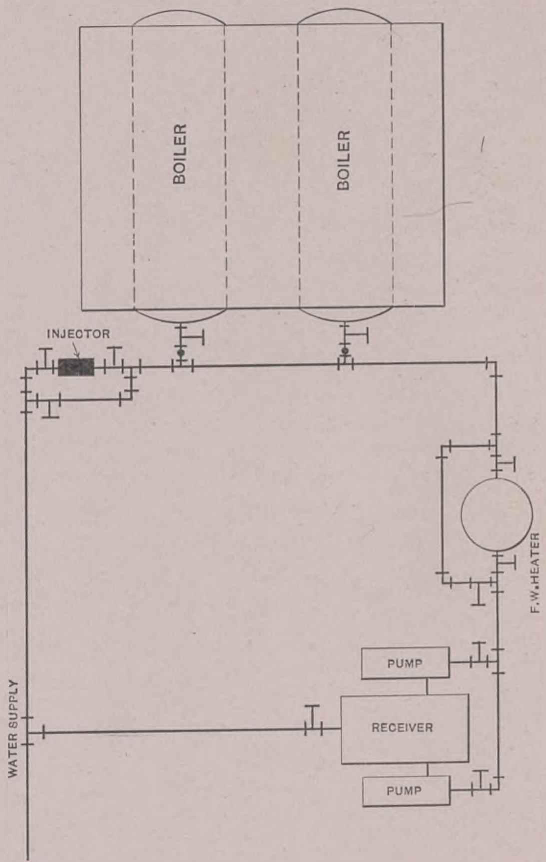


Fig. 37. Feed Connections for Non-condensing Plant.

The method of connecting up the feed apparatus will vary in different cases, but the following diagrams will serve as a basis from which to make up different combinations as may be required.

For simplicity only one piece of apparatus of a kind is shown except in the case of feed pumps, which should always be in duplicate.

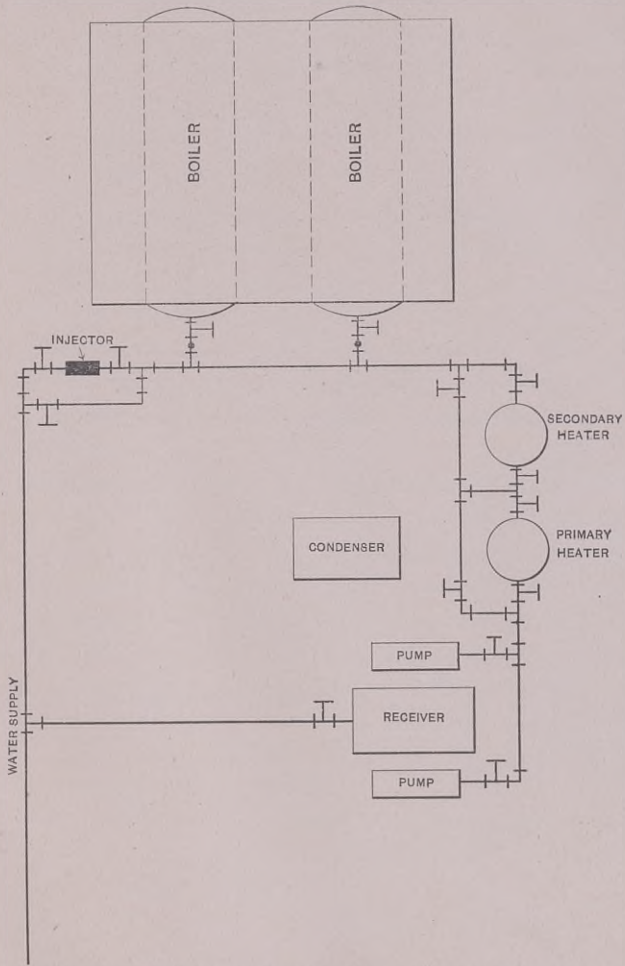


Fig. 38. Feed Connections for Plant with Jet Condenser.

Feed Piping for Non-Condensing Plant.—Fig. 37 shows the feed connections for a non-condensing plant of the simplest kind. The supply main separates into two branches, one leading to the receiving tank and the other to an injector near the front of the boilers. The connection with the tank may have simply a hand valve for supplying fresh water when required, or it may be provided with a float valve for admitting it automatically when the water line in the tank falls below a given level. The discharge

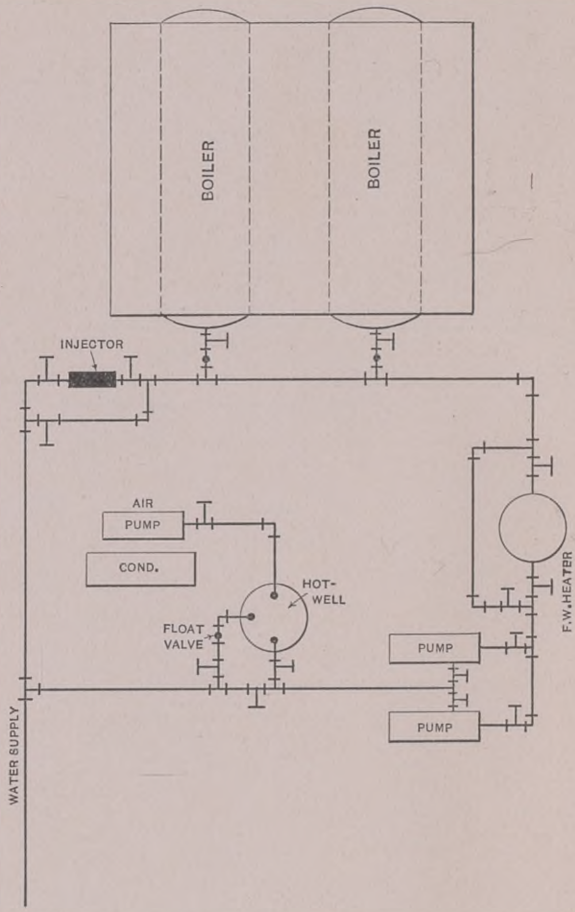


Fig. 39. Feed Connections for Plant with Surface Condenser.

from the feed pump is passed through a closed heater on its way to the boilers. The branch leading to each boiler should be provided with both check and gate valves, the latter being placed next to the boiler and in a position easily reached from the boiler room floor. A by-pass is shown around the injector for admitting water to the boilers directly from the main.

Sometimes the injector is placed on a separate line; this is a good arrangement in large plants, as it admits of any boiler being emptied and refilled from the main, independently of those under steam pressure. All drips, and the returns from the heating system are trapped into the receiving tank. An open heater might be used in this case which would take the place of both the receiving tank and closed heater.

Feed Piping for Condensing Plants.—Fig. 38 shows the arrangement of piping for a plant using a jet condenser in which the discharge water is turned into the sewer. The only change in this case is the addition of a primary heater placed in the main exhaust pipe between the engine and condenser. The discharge from the feed pump is first passed through this heater and then through an auxiliary supplied with exhaust steam from the air and feed pumps.

Fig. 39 illustrates a condensing plant in which a surface condenser is used. The exhaust from the engine is passed through an oil separator and the discharge water from the air-pump turned into a hot-well, from which it is pumped back to the boilers. A feed-water heater taking exhaust steam from the pumps, is used as before. The fresh water supply, high-pressure drips, and return from the heating system are discharged into the hot-well instead of a receiver as before. The pump suction has a cross-connection so that it can take its supply either from the hot-well or directly from the main.

In case an economizer was used, supplying heat from the flue gases, it should be connected into the feed line between the exhaust heater and the boilers.

Size of Steam Pipes.

The size of steam pipes for high-pressure work, where the length of run does not exceed 100 feet, is usually based on the velocity of flow. The maximum commonly allowed is 6,000 feet per minute for supply mains and 4,000 feet for exhaust. In practice it is customary to make the pipes slightly larger than called for by this velocity.

Computing Size of Piping.—The following empirical formulas may be used for computing the size of steam and exhaust pipes of modern engines of good economy, when the cylinder dimensions and speed are known:

For steam pipe,

$$d = D\sqrt{\frac{L \times R}{36{,}000}}$$

For exhaust pipe,

$$d = D\sqrt{\frac{L \times R}{24{,}000}}$$

in which

$d =$ diameter of pipe in inches.
$D =$ diameter of cylinder in inches.
$L =$ length of stroke in inches.
$R =$ revolutions per minute.

A simple method giving a slightly larger pipe than the above, but corresponding well with average modern practice, is to allow 0.12 square inches area per I. H. P. for steam, and 0.18 square inches for exhaust pipe. The factor 0.12 may also be applied with good results to boilers, as 30 pounds of steam per H. P. per hour at 70 pounds pressure represents the average water rate of simple non-condensing engines as well as the quantity furnished by one boiler H. P.

Example.—A power plant consists of six 100 H. P. boilers which supply steam to four 150 H. P. engines. All of the boilers are to be connected with a main drum or header, from which supply pipes are to be carried to each engine. What should be the size of the boiler leads, the main header, and the supply and exhaust connections with the engines?

Size of boiler leads equals $100 \times 0.12 = 12$ sq. in., which corresponds very closely to a 4-in. pipe. The main header is commonly given a sectional area equal to that of all the leads connecting with it, which in this case would call for $600 \times 0.12 = 72$ sq. in., which is slightly less than a 10-in. pipe. Size of steam supplies to engines equals $150 \times 0.12 = 18$ sq. in.; this is somewhat less than the area of a 5-in. pipe, but as $4\frac{1}{2}$ in. is not a standard size, the former would probably be used. The exhaust connections call for $150 \times 0.18 = 27$ sq. in., which corresponds to a 6-in. pipe.

Steam Main with Reservoir near Engine.—In some of the latest high-pressure plants, the pipes leading from the main header to the engines have been made from one to two sizes smaller than called for by the engine builders. These pipes connect with large separators having a cubic capacity about three times that of the high-pressure cylinder and placed close to the throttle valve of the engine. The connection between the separator and cylinder is made the full size called for by the engine. The object of this arrangement is to have a full supply of steam close to the throttle; to provide a cushion near the engine on which the blow caused by the cut-off may be spent, thereby preventing vibrations from being transmitted through the piping system; and, finally to produce a steady and rapid flow of steam in one direction, by having a small pipe leading to the receiver.

Size of Pipe for Given Weight of Steam.—When the length of run is over 100 feet or the main is to supply steam for various purposes which cannot be conveniently expressed in horse power, it is best to reduce the quantity to be supplied to pounds per minute, and assume a permissible drop in pressure at the end of the line. There are several methods of doing this, among which the following has been used with satisfactory results. This is known as D'Arcy's formula, with certain modifications to adapt it to the flow of steam. This formula in its different forms is given below.

$$Q = c\sqrt{\frac{(p - p_1)\,d^5}{wl}}$$

$$W = c\sqrt{\frac{w\,(p - p_1)\,d^5}{l}}$$

$$d = \sqrt[5]{\frac{W^2 l}{c^2 w\,(p - p_1)}}$$

$$p - p_1 = \frac{Q^2 w l}{c^2 d^5}$$

in which

Q = cubic feet of steam per minute.
W = weight of steam per minute.
w = weight of a cubic foot of steam at pressure p.
p = pressure of steam at inlet to pipe, called the *initial* pressure.
p_1 = pressure of steam at outlet of pipe called the *terminal* pressure.
d = diameter of pipe in inches.
l = length of pipe in feet.
c = a constant, depending upon the diameter of pipe.

TABLE XIV.

CONSTANTS FOR FORMULA FOR FLOW OF STEAM.

Diameter of pipe, inches	Value of C	Diameter of pipe, inches	Value of C
1	45.3	5	58.4
$1\frac{1}{4}$	48.2	6	59.5
$1\frac{1}{2}$	50.3	7	60.1
2	52.7	8	60.7
$2\frac{1}{2}$	54.3	9	61.2
3	56.1	10	61.8
$3\frac{1}{2}$	57.1	12	62.1
4	57.8	15	62.6

Table XIV. gives the values of c for different diameters of pipe, and Table XV. the fifth powers of the corresponding pipe sizes. As the computations are somewhat lengthy, the tables of results are given with full directions for their proper use. These may be safely employed for all ordinary work, while the formulas may be resorted to for special cases not covered by the tables.

Table XVI. gives the flow of steam in pounds per minute for pipes of different diameters, and with varying drops in pressure between the supply and discharge ends of the pipe. These quantities are for pipes 100 feet in length; for other lengths the results must be corrected by the factors given in Table XVIII. As the length of the pipe increases, the friction becomes greater, and the quantity of steam discharged in a given time is diminished.

Table XVI. is computed on the assumption that the drop in pressure between the two ends of the pipe equals the initial pressure. If the drop in pressure is less than the initial pressure the actual discharge will be slightly greater than the quantities

TABLE XV.

FIFTH POWERS OF PIPE SIZES FOR USE IN FORMULA.

Diameter of pipe, inches	5th power	Diameter of pipe, inches	5th power
1	1.00	5	31.25
1¼	3.05	6	77.76
1½	7.59	7	168.07
2	32.00	8	327.68
2½	97.60	9	590.49
3	243.00	10	1000.00
3½	522.90	12	2488.32
4	1024.00	15	10485.76

TABLE XVI.

FLOW OF STEAM IN POUNDS PER MINUTE FOR PIPES OF DIFFERENT DIAMETERS AND WITH DIFFERENT DROPS IN PRESSURE.

Diameter of pipe, inches	Drop in pressure, pounds								
	¼	½	¾	1	1½	2	3	4	5
1	0.44	0.63	0.78	0.91	1.13	1.31	1.66	1.97	2.26
1¼	0.81	1.16	1.43	1.66	2.05	2.39	3.02	3.59	4.12
1½	1.06	1.89	2.34	2.71	3.36	3.92	4.94	5.88	6.75
2	2.93	4.17	5.16	5.99	7.43	8.65	10.9	13.0	14.9
2½	5.29	7.52	9.32	10.8	13.4	15.6	19.7	23.4	26.9
3	8.61	12.3	15.2	17.6	21.8	25.4	32	31.8	43.7
3½	12.9	18.3	22.6	26.3	32.5	37.9	47.8	56.9	65.3
4	18.1	25.7	31.8	36.9	45.8	53.3	67.2	80.1	91.9
5	32.2	45.7	56.6	65.7	81.3	94.7	120	142	163
6	51.7	73.3	90.9	106	131	152	192	229	262
7	76.7	109	135	157	194	226	285	339	390
8	108	154	190	222	274	319	402	478	549
9	147	209	258	299	371	432	545	649	745
10	192	273	339	393	487	567	715	852	977
12	305	434	537	623	771	899	1130	1350	1550
15	535	761	942	1090	1350	1580	1990	2370	2720

given in the table, but this difference will be small for pressures up to 10 pounds, and can be neglected as it is on the side of safety. For higher initial pressures, Table XVII. has been prepared. This is to be used in connection with Table XVI. as follows. First find from Table XVI. the quantity of steam which will be discharged through the given diameter of pipe with the assumed drop in pressure; then look in Table XVII. for the factor corresponding to the assumed drop and the higher initial pressure to be used. The quantity given in Table XVI. multiplied by this factor will give the actual capacity of the pipe under the given conditions.

Example.—What weight of steam will be discharged through a 3-in. pipe, 100 ft. long, with an initial pressure of 60 lb. and a drop of 2 lb.

TABLE XVII.

VALUES CORRESPONDING TO HIGH INITIAL PRESSURES TO BE USED IN CONNECTION WITH TABLE XVI.

Drop in pressure, pounds	Initial pressure, pounds						
	10	20	30	40	60	80	100
$\frac{1}{4}$	1.27	1.49	1.68	1.84	2.13	2.38	2.60
$\frac{1}{2}$	1.26	1.48	1.66	1.83	2.11	2.36	2.58
1	1.24	1.46	1.64	1.80	2.08	2.32	2.53
2	1.21	1.41	1.59	1.75	2.02	2.26	2.47
3	1.17	1.37	1.55	1.70	1.97	2.20	2.40
4	1.14	1.34	1.51	1.66	1.92	2.14	2.33
5	1.12	1.31	1.47	1.62	1.87	2.09	2.18

Looking in Table XVI. we find that a 3-inch pipe will discharge 25.4 lb. of steam per minute with a 2-lb. drop. Then looking in Table XVII. we find the factor corresponding to 60 lb. initial pressure and a drop of 2 lb. to be 2.02. Then according to the rule given, $25.4 \times 2.02 = 51.3$ lb., which is the capacity of a 3-in. pipe under the assumed conditions.

Sometimes the problem will be presented in the following way: What size of pipe will be required to deliver 80 lb. of steam a distance of 100 ft. with an initial pressure of 40 lb. and a drop of 3 lb.?

We have seen that the higher the initial pressure with a given drop, the greater will be the quantity of steam discharged; therefore a smaller pipe will be required to deliver 80 lb. of steam at 40 lb. than at 3 lb. initial pressure. From Table XVII. we find that a given pipe will discharge 1.7 times as much steam per minute with a pressure of 40 lb. and a drop of 3 lb., as it would with a pressure of 3 lb. dropping to zero. From this it is evident that if we divide 80 by 1.7 and look in the table under "3 lb. drop" for the result thus obtained, the size of pipe corresponding will be that required.

$$80 \div 1.7 = 47.$$

The nearest number in the table marked "3 lb. drop" is 47.8 which corresponds to a 3½-in. pipe and is the size required.

These conditions will seldom be met with in low-pressure heating, but apply more particularly to combination power and heating plants, and will be taken up more fully under that head.

Table XVIII.

Factors for Pipe Lengths Other than 100 Feet to Use with Table XVI.

Feet	Factor	Feet	Factor	Feet	Factor	Feet	Factor
10	3.16	120	0.91	275	0.60	600	0.40
20	2.24	130	0.87	300	0.57	650	0.39
30	1.82	140	0.84	325	0.55	700	0.37
40	1.58	150	0.81	350	0.53	750	0.36
50	1.41	160	0.79	375	0.51	800	0.35
60	1.29	170	0.76	400	0.50	850	0.34
70	1.20	180	0.74	425	0.48	900	0.33
80	1.12	190	0.72	450	0.47	950	0.32
90	1.05	200	0.70	475	0.46	1000	0.31
100	1.00	225	0.66	500	0.45		
110	0.95	250	0.63	550	0.42		

For lengths of pipe other than 100 ft., multiply the quantities given in Table XVI. by the factors found in Table XVIII.

Example.—What weight of steam will be discharged per minute through a 3½-in. pipe, 450 ft. long, with a pressure of 5 lb. and a drop of ½ lb.?

Table XVI., which may be used for all pressures below 10 lb., gives for a 3½-in. pipe, 100 ft. long, a capacity of 18.3 lb. for the above conditions. Looking in Table XVIII. we find the correction factor for 450 ft. to be 0.47. Then $18.3 \times 0.47 = 8.6$ lb., the quantity of steam which will be discharged if the pipe is 450 ft. long.

Examples involving the use of Tables XVI., XVII. and XVIII.

in combination are quite common in practice. The following shows the method of calculation:

Example.—What size of pipe will be required to deliver 90 lb. of steam per minute a distance of 800 ft., with an initial pressure of 80 lb. and a drop of 5 lb.?

Table XVIII. gives the factor for 800 ft. as 0.35 and Table XVII. that for 80 lb. pressure and 5 lb. drop as 2.09. Then

$$\frac{90}{0.35 \times 2.09} = 123,$$

which is the equivalent quantity we must look for in Table XVI. We find that a 4-in. pipe will discharge 91.9 lb. and a 5-in. pipe 163 lb. As 4½-in. pipe is not commonly carried in stock we should probably use a 5-in. in this case, unless it was decided to use a 4-in. and allow a slightly greater drop in pressure. In ordinary heating work with pressures varying from 2 to 5 lb., a drop of ¼ lb. in 100 ft. has been found to give satisfactory results.

Size of Water Pipes.

Feed Pipe.—The size of feed pipe is usually governed by the discharge outlet of the pump. Special makes of boilers, feed-water heaters, etc., have the size of feed connections fixed, so that in piping up the different pieces of apparatus it is merely a matter of proportioning the pipes to the openings to be connected.

In the case of tubular boilers the size of feed pipe is usually fixed by custom, and depends upon the diameter of the boiler. The dimensions in Table XIX. may be taken as about the average practice.

Table XIX.

Sizes of Feed Pipe.

Diameter of boiler, inches	Size of feed pipe, inches
42	1
48	1
54	1¼
60	1¼
66	1½
72	1½

Proportioning Pipe Sizes.—The common method of proportioning pipe sizes is to make the total sectional area of the branches equal to that of the main, although as a matter of fact it should be somewhat greater. This is true because for a given area and velocity of flow, there will be less frictional resistance in a single large pipe than if the same quantity of water were passed through several smaller pipes having the same total area.

Table XX. gives the internal area in square inches of several sizes of standard wrought iron pipe.

TABLE XX.

INTERNAL AREA OF STANDARD WROUGHT IRON PIPE.

Diameter of pipe, inches	Internal area, square inches	Diameter of pipe, inches	Internal area, square inches
¾	0.53	3	7.4
1	0.86	3½	9.9
1¼	1.5	4	12.7
1½	2.0	5	20.0
2	3.3	6	28.9
2½	4.8	8	50.0

TABLE XXI.

NUMBER AND SIZE OF BRANCH PIPES WHICH A GIVEN MAIN WILL SUPPLY.

Main		Branch
1 in.	will supply	two .... ¾ in.
1¼ in.	"	two .... 1 in.
1½ in.	"	two .... 1¼ in.
2 in.	"	two .... 1½ in.
2½ in.	"	two 1½ in. and one 1¼ in., or one 2 in. and one 1¼ in.
3 in.	"	one 2½ in. and one 2 in., or two 2 in. and one 1½ in.
3½ in.	"	two 2½ in. or one 3 in., and one 2 in. or three 2 in.
4 in.	"	one 3½ in. and one 2½ in., or two 3 in. and four 2 in.
4½ in.	"	one 3½ in. and one 3 in., or one 4 in. and one 2½ in.
5 in.	"	one 4 in. and one 3 in., or one 4½ in. and one 2½ in.
6 in.	"	two 4 in. and one 3 in., or four 3 in. or ten 2 in.
7 in.	"	one 6 in. and one 4 in., or three 4 in. and one 2 in.
8 in.	"	two 6 in. and one 5 in., or five 4 in. and two 2 in.

Table XXI. takes into account the frictional resistance as noted above and shows the number and size of branches which a given main will supply.

The above methods are sufficiently accurate for boiler-room work, where the distances are short, but in the case of long runs of pipe, such as the mains in forced hot-water heating, and the suction and discharge of pumps moving large quantities of water long distances, it is necessary to compute the sizes more accurately.

Flow of Water in Pipes.

If several open vessels containing water are connected by pipes, the water will eventually stand at the same level in all of them, regardless of the length or the size of the connecting pipes.

The pressure exerted by a liquid at any given point is the same in all directions, and is proportional to the depth.

Hydraulic Head.—A column of water at 60° temperature, having a sectional area of 1 square inch and a height of 1 foot, weighs 0.43 pound, and the pressure exerted may be expressed in feet head or pounds per square inch. If a closed vessel is connected by means of a pipe with an open vessel at a higher level, so that it is 10 feet, for example, from the bottom of the first vessel to the surface of the water in the second, the pressure on each square inch of the entire bottom of the lower vessel will be $10 \times 0.43 = 4.3$ pounds, and the pressure per square inch at any given point in the vessel or connecting pipe will be equal to its distance in feet from the surface of the water in the upper vessel, multiplied by 0.43. If a pipe is carried from a reservoir situated on the top of a hill to a point at the foot of the hill a hundred feet below the surface of the water, a pressure of $100 \times 0.43 = 43$ pounds per square inch will be exerted at the lower end of the pipe, provided it is closed. Another way of expressing the same condition is to say the water in the pipe is under a head of 100 feet.

Water Flowing in Pipes.—When the lower end of the pipe is opened and the water begins to flow, the conditions are changed and the pressure in the different parts of the pipe varies with the distance from the open end.

In order for a liquid to flow through a pipe there must be a certain pressure or head at the inlet end. The total head causing the flow is divided into three parts, as follows: First, the *velocity* head, the height through which a body must fall in a vacuum to acquire the velocity with which the liquid enters the pipe; second, the *entry* head, that required to overcome the resistance to entrance into the pipe; third, the *friction* head, due to the frictional resistance to flow within the pipe. In the case of long pipes and low heads the sum of the velocity and entry heads is small, compared with the friction head, and in ordinary work may usually be neglected.

Friction Head.—Table XXII. gives the friction head for different velocities of flow through pipes of different diameters, and the corresponding number of gallons discharged per minute. The friction heads are given in pounds per square inch, and represent the pressure required to force water at the given velocity through a horizontal pipe 100 feet in length.

As the frictional resistance is proportional to the length, the friction head for any other length of run can be found by multiplying the number given in the table by the given length divided by 100. That is, for 1,000 feet, multiply by 10, and for 50 feet, multiply by 0.5.

The use of Table XXII. can best be shown by one or two practical illustrations.

Example.—It is desired to circulate 250 gallons of water per minute through a heating main 500 ft. long, at a velocity of about 12 ft. per second. What size pipe will be required, and what pressure per square inch must be exerted by the pump to overcome the frictional resistance?

Looking in the table along the line corresponding to 250 gallons we find that a 3-in. pipe will discharge this quantity at a velocity of 11.3 ft. per second, with a friction head of 7.8 lb. This, however, is for a pipe 100 ft. in length, and for 500 ft. the required pressure would be $5 \times 7.8 = 39$ lb. per sq. in.

Example.—A pump having a 2-in. discharge is used to force water into a tank situated on an elevation 100 ft. above it and 800 ft. distant. What pressure per square inch must the water piston of the pump exert to deliver 50 gallons per minute?

The pressure to be overcome by the pump consists of two parts, the weight of a column of water 100 ft. high, and the frictional

Table XXII.

Gallons Discharged per Minute, Friction Heads and Velocities for Pipes of Different Diameters.

Velocity in feet per second. Friction head in pounds per square inch.

Gallons per minute	¾-inch		1-inch		1¼-inch		1½-inch		2-inch		2½-inch		3-inch		4-inch		6-inch		8-inch		Gallons per minute
	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	Velocity	Friction head	
5	3.6	3.3	2.0	0.8	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	5
10	7.2	13.0	4.1	3.2	2.6	1.0	....	....	....	....	....	....	....	....	....	....	....	....	....	....	10
15	10.9	23.7	6.1	7.0	3.9	2.4	2.7	1.0	....	....	....	....	....	....	....	....	....	....	....	....	15
20	14.5	50.4	8.2	12.3	5.2	4.1	3.6	1.7	....	....	....	....	....	....	....	....	....	....	....	....	20
25	18.1	78.0	10.2	19.0	6.5	6.4	4.5	2.6	....	....	....	....	....	....	....	....	....	....	....	....	25
30	....	....	12.3	27.5	7.8	9.1	5.4	3.7	3.1	0.9	....	....	....	....	....	....	....	....	....	....	30
35	....	....	14.3	37.0	9.1	12.0	6.4	5.0	3.6	1.2	....	....	....	....	....	....	....	....	....	....	35
40	....	....	16.3	48.0	10.4	16.1	7.3	6.5	4.1	1.6	....	....	....	....	....	....	....	....	....	....	40
45	....	....	....	....	11.7	20.2	8.2	8.1	4.6	2.0	....	....	....	....	....	....	....	....	....	....	45
50	....	....	....	....	13.1	24.9	9.1	10.0	5.1	2.4	3.3	0.8	2.3	0.3	....	....	....	....	....	....	50
75	....	....	....	....	19.6	56.1	13.6	22.4	7.7	5.3	4.9	1.8	3.4	0.7	....	....	....	....	....	....	75
100	....	....	....	....	....	....	18.2	39.0	10.2	9.5	6.5	3.2	4.5	1.3	2.5	0.3	....	....	....	....	100
125	....	....	....	....	....	....	....	....	15.8	14.9	8.2	4.9	5.7	2.0	3.1	0.5	....	....	....	....	125
150	....	....	....	....	....	....	....	....	15.3	21.2	9.8	7.0	6.8	2.8	3.8	0.7	....	....	....	....	150
175	....	....	....	....	....	....	....	....	17.1	28.1	11.4	9.5	7.9	3.8	4.5	1.0	....	....	....	....	175
200	....	....	....	....	....	....	....	....	20.4	37.5	13.1	12.5	9.1	5.0	5.1	1.2	....	....	....	....	200
250	....	....	....	....	....	....	....	....	....	....	16.3	19.7	11.3	7.8	6.4	1.9	2.8	0.3	....	....	250
300	....	....	....	....	....	....	....	....	....	....	19.6	28.1	13.6	11.2	7.7	2.7	3.4	0.4	....	....	300
350	....	....	....	....	....	....	....	....	....	....	....	....	15.9	15.2	8.9	3.6	4.0	0.5	....	....	350
400	....	....	....	....	....	....	....	....	....	....	....	....	18.2	19.5	10.2	4.7	4.5	0.6	....	....	400
450	....	....	....	....	....	....	....	....	....	....	....	....	....	....	11.5	6.0	5.1	0.8	....	....	450
500	....	....	....	....	....	....	....	....	....	....	....	....	....	....	12.8	7.4	5.7	1.0	3.2	0.2	500
750	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	8.5	2.2	4.8	0.5	750
1000	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	11.3	3.9	6.4	0.9	1000
1250	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	8.0	1.5	1250
1500	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	9.6	2.1	1500

resistance within the pipe. The first of these is equal to $100 \times 0.43 = 43$ lb. per sq. in., and the second, from the table, is found to be 2.4 lb. for a pipe 100 ft. long, or $8 \times 2.4 = 19.2$ lb. for 800 ft. The total pressure is therefore $43 + 19.2 = 62.2$ lb. per sq. in.

Insulation.

Steam pipes, separators, heaters, etc., should be covered with some good insulating material to reduce the amount of condensation, and incidentally to prevent, to some extent, overheating the engine and boiler rooms.

Materials Used.—Various materials are used for this purpose, the more common being carbonate of magnesia, asbestos, hair-felt, cork, and mineral wool.

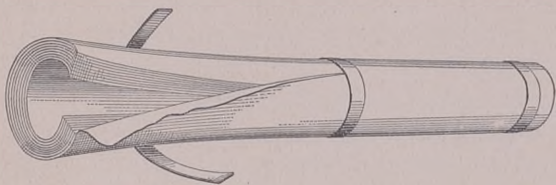


Fig. 40. Pipe Covering.

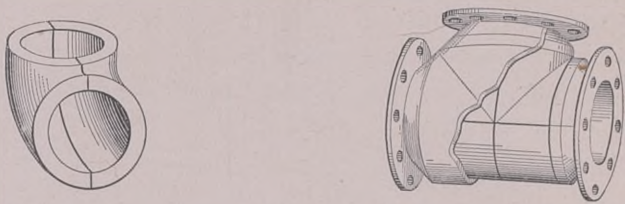
These are made up in various combinations and formed into canvas-covered sections about 3 feet in length, as shown in Fig. 40. After being placed upon the pipe, the canvas flaps are pasted down and light metal bands drawn tightly around the ends and middle of each section to hold it in place.

Valves and fittings are covered either with moulded or plastic material. The former consists of a mould of proper size and shape to enclose the fitting, made in two parts and held in place by a canvas covering and metal bands. One of these is shown in Fig. 41.

Plastic Covering is made by applying several thin coats of asbestos or magnesia in the form of a paste directly to the fitting, each being allowed to dry before the next is applied. This is given the proper shape, and after hardening is covered with canvas securely pasted to hold it in place.

Extended surfaces, like small boilers, heaters, smoke pipes, etc., are usually covered with plastic material applied to a wire netting secured to the metal surface. A smooth finish is given when nearly dry by rubbing with a trowel.

Sometimes a lagging of insulating blocks an inch or so in thickness is first wired to the metal surface, and this finished with a coat of plastic material. Fig. 42 shows this method of insulation applied to a large fitting.



Figs. 41 and 42. Covering for Fittings.

Pipe coverings are usually made from 1 inch to 1¼ inches in thickness, this being the economical limit; any additional heat saved by using a thicker covering being slight when compared with the increased cost.

Plastic covering possesses the advantage of being applicable to any shape of pipe or fitting, as well as boilers, heaters, separators, etc., but the covering cannot be removed for the inspection of joints and seams without being destroyed. Sectional covering can be taken off and replaced without damage, and is used almost exclusively for straight runs of pipe. Moulded fittings are commonly used in the best class of high-pressure work, especially for flanges, while a plastic covering is usually sufficient in the case of low-pressure heating systems.

Selection of a Covering.—In selecting a covering, its durability should be considered as of equal importance with its non-conducting properties. Many coverings which show a good efficiency when new, deteriorate quite rapidly when placed upon a pipe line connected with high-speed engines or other machinery causing vibration.

Coverings containing corrosive substances, such as sulphate of lime (plaster of Paris) and sulphur should always be avoided. Carbonate of lime (chalk) is harmless so far as corrosion is concerned, but is reduced to a powder by vibration and thus rendered useless. Some of the inferior grades of mineral wool are apt to contain sulphur, which is likely to attack the pipe if it becomes moist.

Carbonate of magnesia and asbestos fiber both make durable and efficient coverings when properly made up, and in specifying, the words "carbonate" and "fiber" should always be mentioned when referring to these materials.

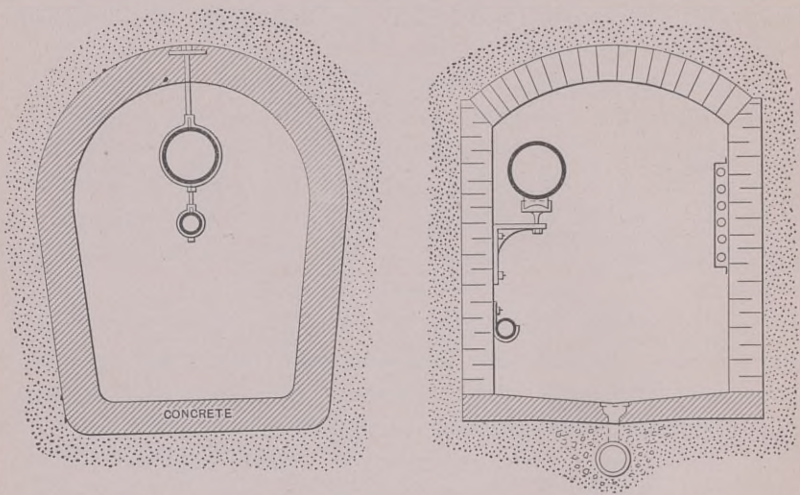
Cork makes a good covering when properly prepared. The granulated material is subjected to a high pressure in iron moulds at a temperature of about 500°. It commonly has a thin layer of asbestos next to the pipe and is provided with a canvas cover the same as other forms. This is especially adapted to places exposed to dampness, as the cork is impervious to moisture.

Heat Loss from Pipes.—The heat loss from bare pipes varies from 2½ to 3 B. T. U. per square foot of surface per hour, for each degree difference in temperature between the steam and surrounding air, depending upon the size of pipe and the freedom with which the air circulates about it. A series of tests made some years ago at the Massachusetts Institute of Technology upon a dozen or more commercial coverings showed that from 75 to 84 per cent of the heat lost from the bare pipe was saved. Taking the average as 80 per cent, and assuming a loss of 3 B. T. U. per square foot per degree difference per hour, the saving to be made in any particular case can be easily approximated.

Underground Conduits.

There are various forms of conduits employed for carrying pipes underground where isolated buildings are supplied with steam from a central plant.

Arched Conduit.—The best type will depend upon circumstances. For high-pressure mains of large size, where the distance is not too great, an arched tunnel of brick or concrete is the best. This should be large enough for a person to pass through easily for purposes of inspection or for repairs. The pipe may be supported from hangers attached to plates embedded in the masonry of the arch, or adjustable brackets may be used, anchor-bolted to the side wall, as shown in Figs. 43 and 44. Mains carried in tunnels of this kind should be protected with a good form of sectional covering, coated with asphaltum or a good waterproof paint.



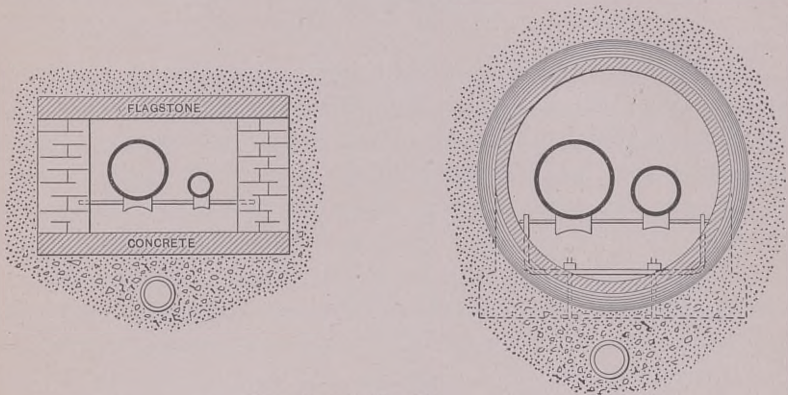
Figs. 43 and 44. Pipe Conduits.

Other Forms of Conduits.—A cheaper form of conduit which may be used where the distance would make a tunnel too expensive is shown in Fig. 45.

This consists of a layer of concrete 3 or 4 inches in thickness, with side walls of brick or concrete, and a covering of slate or flagstone laid in cement. The pipes are supported upon rolls as shown.

When possible a 3-inch or 4-inch tile under-drain should be provided. This should be laid to a proper grade, have open joints, and be surrounded with stones and coarse gravel. Provision must be made at the outlet for carrying away the surface water.

Sectional covering is sometimes used in conduits of this kind, but a better method is to pack the space around the pipe with a mixture of granulated cork and infusorial earth, or with a preparation of asbestos, the latter being considered preferable for high pressure work.



Figs. 45 and 46. Pipe Conduits.

Another form quite frequently used is the split tile conduit shown in Fig. 46. The sections are formed with grooves along the sides and may be easily split apart. The lower halves are first laid, after which the pipes are run and the upper halves tightly cemented in place. As each section is completed it is packed with insulating material in the same manner as previously described.

The conduit should be surrounded with gravel or coarse sand and under-drained in the manner indicated. This is a patented article, controlled by the H. W. Johns-Manville Company.

Conduits of this kind should be large enough to allow an inch or more between the pipes, and about 3 inches between the pipes and walls of the conduit in order to provide sufficient insulation.

CHAPTER V.

ELECTRICITY.

The subject of electricity and its uses in connection with power and lighting must necessarily be taken up in the briefest possible manner in a book of this kind. The complete installation of lighting and power plants lies within the field of the electrical engineer, but the steam engineer often has to make provision for these in designing his boiler plant, and the architect, also, in laying out the boiler and engine rooms must be familiar to a certain extent with the floor space required for different kinds of apparatus connected with the mechanical and electrical equipment of his building.

As electric motors are often used for driving fans and blowers, it becomes necessary for the ventilating engineer to familiarize himself with the various kinds of electrical equipment used in this class of work.

The following pages are intended to give in a brief manner some of the more important principles of electricity, together with its application to power, lighting and heating.

Electricity is an invisible agent which manifests itself in various ways. Its exact nature is not known, but the effects produced by it, the methods of controlling it, and the laws governing its action are becoming well understood.

Electricity is of two kinds, *static* and *dynamic.*

Static electricity relates to that form which exists upon bodies in the form of charges, and is produced by friction. It is of two kinds, *positive* and *negative.* Bodies charged with the same kind repel each other, while those charged with opposite kinds attract each other. If two bodies charged with equal quantities of positive and negative electricity are brought sufficiently near together, the two charges will neutralize each other. If the charges upon the two bodies are not equal, then only a sufficient quantity will pass from that having the greater charge, to neutralize that of the other, and the balance will remain as a smaller charge upon the first body.

Dynamic electricity considers the flow of electricity in currents. This form is produced by dynamos and is used for power and lighting. It may also be produced chemically by the use of batteries when required only in small quantities.

Electro-motive Force.—When a difference of electrical potential, or pressure, exists between two points, there is said to exist an *electro-motive force,* or a tendency for a current to flow from one point to the other. In a voltaic cell, one plate is at a different potential from the other, which gives rise to an electro-motive force between them. In a dynamo a difference of potential exists between the two poles. Electro-motive force may be likened to the pressure caused by a difference in level of two bodies of water connected by a pipe. The pressure tends to force the water through the pipe, and the electro-motive force tends to produce a current. This pressure is called *voltage.* In speaking of electro-motive force, the abbreviation E. M. F. is commonly used.

Current.—A current of electricity flows when two points at a different potential are connected by a wire or other conductor. In the same manner water flows from a higher to a lower level when a path is provided. In either case the flow can take place only when a connecting path exists. Therefore, to produce a current, it is necessary to have an electro-motive force and a closed circuit.

Resistance.—That property of matter which opposes or resists the flow of electricity through it is called *resistance.*

Ampere.—The unit of current is the *ampere,* and is the strength of current, which, when passed through a solution of silver nitrate in accordance with standard specifications, will deposit silver at the rate of 0.001118 of a gramme per second. Symbol, I.

Ohm.—The unit of resistance is the *ohm,* and is the resistance produced by a uniform column of mercury, 106.3 centimeters long, and 14.4521 grammes in mass, at the temperature of melting ice. Symbol, R.

Volt.—The volt is the unit of electro-motive force, and equals 0.6974 of the electro-motive force of a Clark standard cell at 15° C. Symbol, *E*.

The ampere, ohm and volt are defined in terms of one another as follows: An ampere is the amount of current which will flow through a resistance of one ohm when the electro-motive force is one volt.

An ohm is the resistance of a conductor through which a current of one ampere will pass when the electro-motive force is one volt.

A volt is the electro-motive force required to cause a current of one ampere to flow through a resistance of one ohm.

Energy.—Whenever a current flows, a certain amount of energy is expended, and this may be transformed into heat, or mechanical work, or may produce chemical changes. The unit of mechanical energy is the foot pound, and is the work done in raising a pound weight one foot in height. From this it is evident that a force acting through space represents work, and that the work done in any particular case is obtained by multiplying the force acting by the distance moved through. Electrical work may be determined in a corresponding manner by knowing the amount of electricity transferred through a given difference of potential.

Power.—Power is the rate of doing work and expresses the amount done in a given time.

Other units used in electrical calculations are the *coulomb*, *joule* and *watt*.

Coulomb.—A *coulomb* is the unit of quantity, and represents the amount of electricity transferred by a current of one ampere in one second. Symbol, *Q*.

Joule.—A *joule* is the unit of work, and is equivalent to the energy expended in one second by a current of one ampere passing through a resistance of one ohm. Symbol, *W*.

Watt.—A *watt* is the unit of power, and is equivalent to the work done at the rate of one joule per second. Symbol, *P*.

For convenient reference the symbols are given below in tabular form.

TABLE XXIII.

Unit of.	Name.	Symbol.
Current	Ampere	I
Resistance	Ohm	R
E. M. F.	Volt	E
Quantity	Coulomb	Q
Work	Joule	W
Power	Watt	P

Using the above symbols for the units, the relation between them may be expressed.

(*a*) $I = \frac{E}{R}$

(*b*) $Q = It.$

(*c*) $W = QE.$

(*d*) $W = I^2Rt.$

(*e*) $P = IE.$

The use of these equations may be illustrated by a few practical examples. A current of 20 amperes flows through a circuit for 2 hours; what quantity of electricity is delivered?

Two hours $= 7{,}200$ seconds; then from (*b*) we have $20 \times 7{,}200 = 144{,}000$ coulombs.

The coulomb is also called the ampere second. The quantity of electricity delivered in one hour by a current of one ampere is called an ampere hour, and is equal to 3,600 coulombs.

With a potential difference of 110 volts and a current of 15 amperes, what energy is expended in 20 minutes? Work is expressed by the product of quantity and potential difference. The time in seconds is $20 \times 60 = 1{,}200$. Substituting the known values in equation (*c*) we have $(15 \times 1{,}200) \times 110 = 1{,}980{,}000$ joules.

A 112-volt incandescent lamp has a resistance of 120 ohms; what power is absorbed by it? We know from equation (*a*) that the current is $\frac{112}{120} = 0.933$ amperes, and substituting this in equation (e) we have $112 \times 0.933 = 104.5$ watts. The watt is sometimes called the volt-ampere.

The *kilowatt,* which is equal to 1,000 watts, is the unit employed almost exclusively in practical work. Its symbol is Kw.

The kilowatt-hour is a common unit of energy, and represents the work done in one hour when the power acting is one kilowatt.

Equivalence of Electrical Energy in Heat Units.—Whenever there is any resistance to the flow of a current there is always a certain amount of electrical energy transformed into heat. The entire current may be changed into heat or only a part of it. The energy which appears as heat raises the temperature of the conductor an amount depending upon the form and area of its radiating surface and upon the surrounding medium. This result is taken advantage of in electric heating. When the resistance of a circuit, the amount of current, and the time are known, the energy or work done in joules may be found by equation (d).

The unit of heat commonly used in electrical measurements is the *calorie,* and is the amount of heat required to raise the temperature of 1 gramme of water 1° C. This is equal to $\frac{1}{252}$ of a B. T. U. By careful investigation it has been found that the energy in one joule is equivalent to 0.24 of a calorie, when changed into heat. From the above it is an easy matter to compute the heat given off by any conductor, if we know its resistance and the current flowing through it.

Example.—An electric heater has a coil, the resistance of which is 3 ohms; how many B. T. U. will be given off per hour by a current of 20 amperes? From equation (d) we have

$W = 20^2 \times 3 \times 3{,}600 = 4{,}320{,}000$ joules, or
$4{,}320{,}000 \times 0.24 = 1{,}036{,}800$ calories, or
$1{,}036{,}800 \div 252 = 4{,}114$ B. T. U.

Equivalence of Electrical Energy in Mechanical Units.—The common unit of mechanical energy is the foot pound, and from experiment it has been found that 1 joule is equivalent to 0.7373 of a foot pound; that is, the same amount of heat will be developed by 1 joule as by 0.7373 of a foot pound of work. As

1 horse power is equal to 550 foot pounds of work per second, it follows that it is also equal to $\frac{550}{0.7373} = 746$ joules per second.

According to the definitions previously given, energy expended, or work done, at the rate of 1 joule per second is equivalent to 1 watt of power; hence, if 746 joules per second equal 1 horse power, then its equivalent, 746 watts, must equal 1 horse power.

Therefore, to find the equivalent of mechanical power in electrical power, multiply the horse power by 746, and to find the equivalent of electrical power in mechanical power, divide the number of watts by 746, or more briefly:

$$\text{horse power} \times 746 = \text{watts},$$
$$\text{watts} \div 746 = \text{horse power}.$$

Example.—An electric motor takes a current of 196 amperes from a 500-volt circuit; what is the equivalent in horse power?

Watts $= EI = 500 \times 196 = 98{,}000$, and the equivalent horse power $= \frac{98{,}000}{746} = 131$.

CHAPTER VI.

GENERATORS.

The term generator or dynamo is commonly applied to a machine which converts mechanical energy into electrical energy.

In order to understand the principles upon which a dynamo operates it will be necessary to discuss briefly the subjects of magnetism and induction.

Magnetism.—The space surrounding a magnet is subject to its influence and is called its magnetic *field*. This field is made up of what are called lines of magnetic force, and which pass from

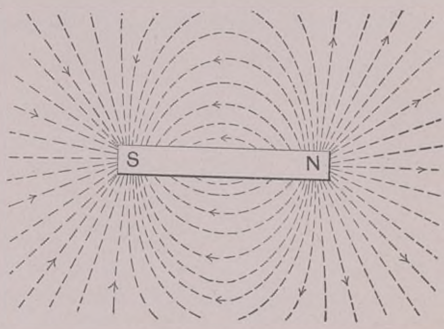


Fig. 47. Magnetic Field of Bar Magnet.

one end or *pole* of the magnet to the other. If the magnet is a straight bar the lines pass from the north to the south pole in the manner illustrated in Fig. 47. The number of lines of force per unit area indicates the strength of the field.

Electro-Magnet.—Whenever a current of electricity is passed through a conducting rod or wire a magnetic field is produced, in which the lines of force take the direction shown in Fig. 48. If the wire is in the form of a spiral or coil, the lines pass through the center, parallel with the axis, as indicated in Fig. 49. By winding the coil of wire around a soft iron core the number of lines, or in other words, the strength of a field is greatly increased. This arrangement constitutes an electro-magnet, which in various forms is an important part of all dynamos and motors.

Induction.—If passing an electric current through a conductor produces a magnetic field, we might naturally expect that creating a magnetic field about a conductor would produce an electric current, and this is found to be true.

Currents generated in this manner are called *induced* currents, and the phenomena of induction is the fundamental principle upon

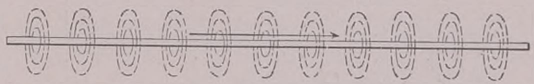


Fig. 48. Magnetic Lines of Force Surrounding an Electric Current.

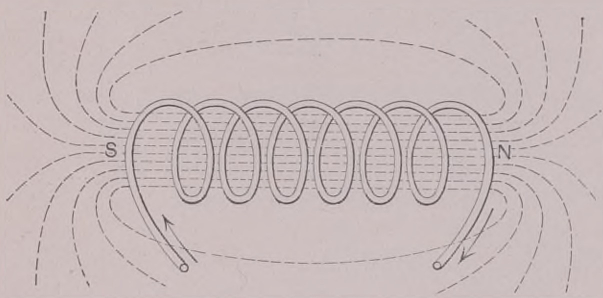


Fig. 49. Magnetic Field of a Solenoid.

which all dynamos operate. The changes in the magnetic field necessary to produce a current in the conductor are only relative; that is, the change may be due to an increase or decrease in the strength of field, a movement of the conductor across the field in such a manner as to cut the lines of force, or a movement of the field about the conductor.

Direction of Current.—Let the dots in Fig. 50 represent the lines of force in a uniform magnetic field passing out through the paper toward the observer. Let *C* be a conductor sliding on the bars *A* and *B* which are connected by the wire *D* to form a closed circuit through *C*.

Now if *C* be moved downward on the bars so as to cut the lines of force, an E. M. F. will be produced in the conductor, causing a current to flow from right to left, which will pass around the circuit as shown by the arrows. If *C* be moved upward, the cur-

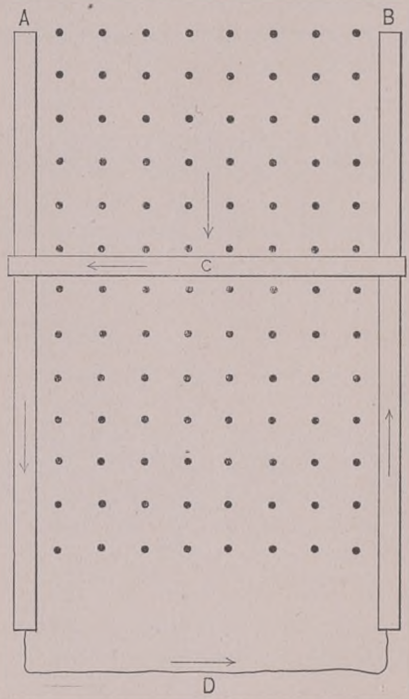


Fig. 50. E. M. F. Developed by Cutting Magnetic Lines of Force.

rent will flow in the opposite direction. If moved endwise, or in a direction parallel with the lines of force, no current will be induced, for in order to produce an E. M. F. and resulting current, it is necessary for the conductor to *cut* the lines of force.

Electro-motive Force Produced.—The amount of E. M. F. or voltage produced, depends upon the number of lines cut in unit of time, and varies with the strength of field, the speed with which the conductor moves across it, and the length of the conductor.

Let Fig. 51 represent a top view or plan of the same magnetic field, so that the lines of force appear as lines instead of dots as in Fig. 50. The direction of the lines is toward the observer as before.

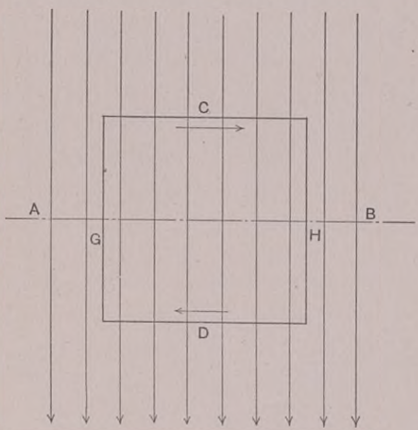


Fig. 51. E. M. F. Induced by Rotating Loop in a Magnetic Field.

The conductor in this instance is a coil or closed circuit of wire, and rotates on the axis *A B* instead of sliding on side bars as before. Now let the coil be rotated on its axis so that the side *D* passes downward across the lines of force; a current will tend to flow toward the left as before. In the meantime the side *C* of the coil is rising and cutting the lines in the opposite direction, and so inducing a current toward the right.

As the sides *G* and *H* rotate in planes parallel with the lines of force, no E. M. F. will be generated in them, and they simply act as conductors for the currents induced in *C* and *D*. As the E. M. F. generated in the two conductors tends to produce currents in opposite directions in opposite sides of the loop, it is evident that the result will be the generation of a current through the coil, having an E. M. F. twice that produced by the single conductor in Fig. 50, provided the lengths of the conductors are the same in each case, and cut the lines of force at the same rate of speed.

Alternating Current.

Effect of Rotating a Closed Conductor in a Magnetic Field.—Let Fig. 52 be a side view of the same magnetic field and rotating coil. When in a horizontal position as shown by the heavy line, the sides *C* and *D* are passing directly across the lines of force at right angles, and are therefore cutting the maximum number per unit of time and producing the greatest E. M. F. As the coil rotates *C* and *D* cross the lines at angles more and more acute, which has the effect of reducing the number of lines per unit of area, or in other words, reducing the E. M. F. When the coil reaches a vertical position as shown by *C′ D′* the conductors are moving in planes parallel with the lines of force and no E. M. F. is generated.

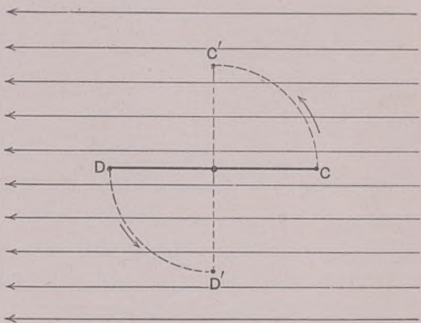


Fig. 52. Changes in E. M. F. Induced in a Loop during one Rotation.

As soon as the coil passes the vertical position, *C* begins to cut the lines in a *downward* direction and *D* in an *upward* direction, which is the reverse of the first part of the rotation, and therefore, the current flows through the coil in the opposite direction.

Successive Stages in a Cycle.—Having seen the general effect of rotating a closed conductor in a uniform magnetic field, let us now follow the different stages in logical order. Starting with the coil in a vertical position as shown by the line *C′ D′* in Fig. 52, the conductors are moving in planes parallel with the lines of force and no E. M. F. is being generated.

As the coil leaves the vertical position the conductors cut the lines of force in increasing numbers until it reaches a horizontal position, where the E. M. F. is at a maximum. Passing this point the E. M. F. becomes less and less until the coil reaches the reverse vertical position, at which point it is zero. Continuing the rotation past this point, the direction of the current reverses, as already described, and the E. M. F. increases until it reaches a maximum at the horizontal position of the coil; it again reduces and becomes zero at the original starting point. The changes which take place in the E. M. F. and resulting current during a single revolution of the coil, as just described, constitute a cycle and illustrate the generation of an alternating current in its simplest form.

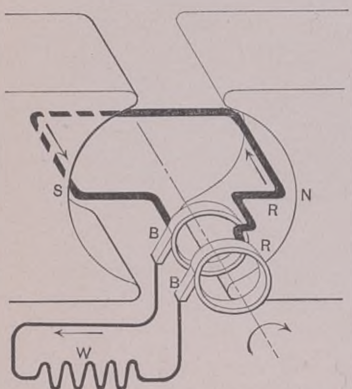


Fig. 53.

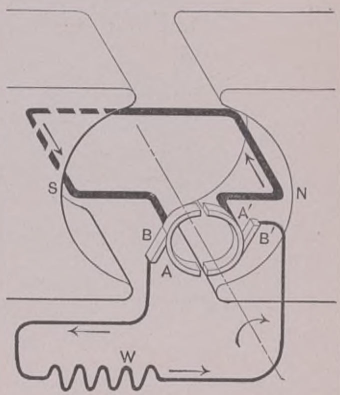


Fig. 54.

Alternating Current Generator.—In order to lead the current through an external circuit for lighting or other purposes the ends of the rotating coil or *armature,* as it is called, are connected with *collecting rings R R*, as shown in Fig. 53. Pressing against these rings as they revolve, are copper or carbon *brushes B B,* connecting with the external circuit *W,* as shown. From the above it is plain that as the current is generated in the armature it must pass through the rings and external line in order to complete the circuit. The magnetic field in this case is produced by the poles of a magnet (N S), between which the armature revolves.

Direct Current.

Generation of the Current.—The alternating current induced in the armature may be changed to a *direct* current in the external circuit by the use of a device called a *commutator*. Its simplest form is shown in Fig. 54, and consists of a split copper ring, with the two segments insulated from each other, and each segment attached to one end of the revolving coil or armature.

Although an alternating current is generated in the armature, the commutator changes it to one which is always in the same direction through the external circuit.

For the position of the coil shown in Fig. 54 its current will be in the direction indicated, and will pass to segment A, brush B,

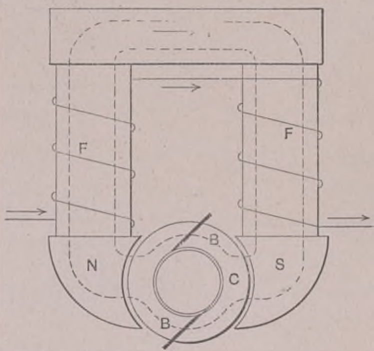


Fig. 55. Diagram of Electric Generator.

through the external circuit to brush B' and segment A' to the coil. As the coil continues to rotate the E. M. F. gradually decreases until 90° from the position shown, when it becomes zero. At this time the segments are located so that the brushes are about to break contact with one segment and make contact with the other. Further rotation induces an E. M. F. in the opposite direction, but the segments have then passed from one brush to the other, and the direction of current in the external circuit therefore remains unchanged. That is, when the current in the coil is in the direction indicated, segment *A* will *deliver* current to brush *B*, but when it is in the opposite direction segment *A* will be under brush *B'* and *receive* current from it.

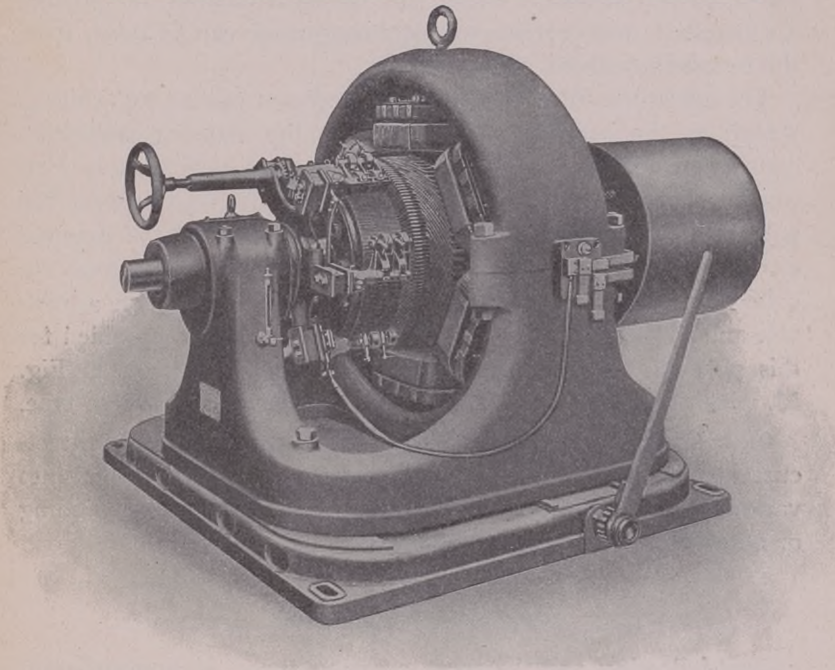


Fig. 56. Compound Wound Generator, Belted Type.

Parts of a Generator.

The essential parts of a generator, as we have learned, are the field magnets, armature, collecting rings in the alternator, and commutator in the direct-current machines, and the brushes. The generator in its simplest form is shown in diagram in Fig. 55. A current is passed through the winding around the *cores* *F F* to produce the magnetic field in which the armature coils rotate. A path for the magnetic lines is provided by the iron cores, the *yoke y*, the pole pieces *N S*, and the armature, as indicated by the dotted lines.

Generators are made both bipolar and multipolar. In the case of direct-current machines the field magnets are made stationary.

Alternators are made with both stationary and revolving fields. The latter type is especially adapted to high voltages, and as the armature is stationary, except for the field current, no brushes are required, and currents of large magnitude can be taken from the terminals without difficulty.

The armature, instead of being made up of one or two coils as shown in the preceding diagrams for the sake of simplicity, consists of a large number of interconnected coils upon a soft-iron core, which serves to conduct the lines of force between the poles of the magnet. The current is conducted to the external circuit through the brushes *B B,* which press lightly upon the collecting rings or commutator *C.* The brushes are made adjustable and are carried by *brush-holders* or on a *rocker,* provided for this purpose. A generator in practical form is shown in Fig. 56, which represents a machine of the multipolar belt-driven type.

Classification of Dynamos.—Dynamos are divided into direct-current machines and alternators, and these are sub-divided into various types which are usually designated by the field winding or other details of construction.

Direct-Current Dynamos.

The following are the most common types of direct-current machines.

Separately Excited Dynamo.—A separately excited dynamo is one having its field coils excited from some outside source, such as a battery or another dynamo. (Fig. 57.)

Series Dynamo.—In this type the main current from the armature is passed through the field coils and then to the external circuit. This machine is adapted only to arc lighting. (Fig. 58.)

Shunt Dynamo.—In the shunt wound machine the current from the armature has two paths through which to flow. One is through the external circuit and the other through the field coils. The current divides at the positive brush and part passes through the external circuit to the negative brush, and a smaller portion passes through the field coils. Dynamos of this type are better adapted to practical service such as lighting, supplying current to motors, etc., than the series machine. (Fig. 59.)

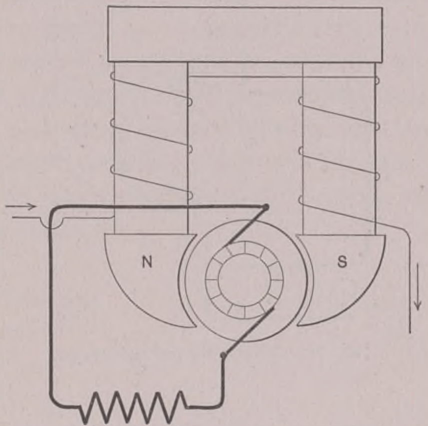


Fig. 57. Separately Excited Generator.

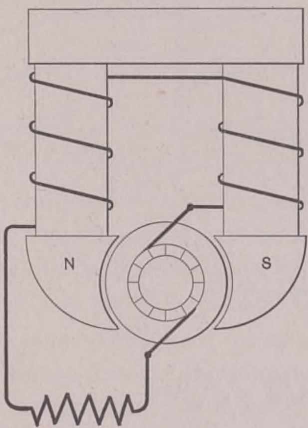


Fig. 58. Series Connected Generator.

Compound Dynamo.—This has a combination of the series and shunt windings. In addition to the shunt winding, connected from brush to brush, the main current is also passed through a few turns of large wire in series with the external circuit.

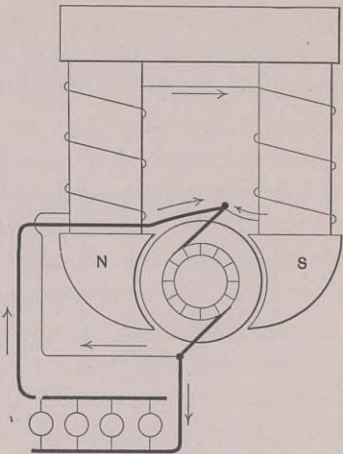


Fig. 59. Shunt Wound Generator.

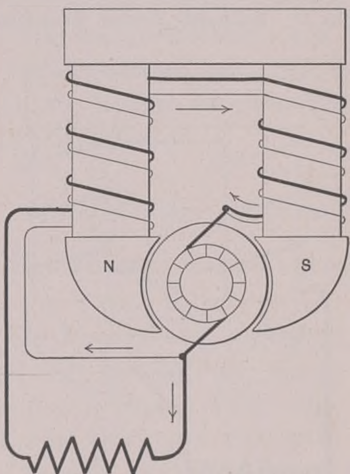


Fig. 60. Compound Wound Generator.

This machine is practically self-regulating and is used almost entirely for incandescent lighting and power. (Fig. 60.)

Direct-current dynamos are made both for constant potential and for constant current. The former supply a varying current at a constant voltage, and the latter a constant current at a varying voltage.

As the output of a dynamo is measured by the product of the voltage times the strength of current in amperes, it makes no difference in the amount of energy delivered, which is the variable factor, so long as the product remains the same

In furnishing a current for power and lighting, the generator is subjected to a varying load. With the first type of machine the voltage remains constant while the current varies to meet the demand; with the second type the current remains constant while the voltage changes.

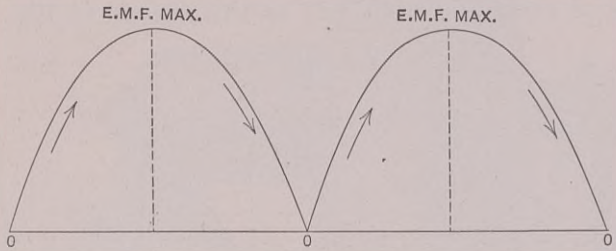


Fig. 61. Showing Rise and Fall of E. M. F. during One Rotation of Coil.

The driving power required for equal loads is the same in either type of machine It has been found in practice, however, that for various reasons the first method is best adapted to incandescent lighting, and the second to arc lighting. Power distribution has occasionally been accomplished by the second method, but the first is now almost universally used.

Curves of E. M. F.—The E. M. F. generated during a single revolution of the armature may be shown graphically by a curve, in which horizontal distances along a given line represent different points in the rotation of the armature, and vertical distances from this line show the E. M. F. at any given point. The curve of E. M. F. from a direct-current machine having a two-part commutator and an armature made up of a single coil is shown in Fig. 61.

Starting when the conductors of the rotating coil are moving in planes parallel with the lines of force, the E. M. F. will be zero. As the coil rotates it will cut more and more lines until the E. M. F. reaches a maximum when it has moved through an arc of 90°, and is cutting the lines at right angles. Passing this point it again reduces until it becomes zero, when the coil has passed through an arc of 180° and the conductors are again moving through planes parallel with the lines of force. The last half of the revolution will generate a duplicate curve, bringing the E. M. F. back to zero at the starting point. A current produced in this manner is called a *pulsating current.*

Production of a Constant Current.—If the armature is made up of two coils placed at right angles to each other so that the E. M. F. generated by one is at a maximum, while that produced by the other is at zero, the result will be that shown in Fig. 62, in

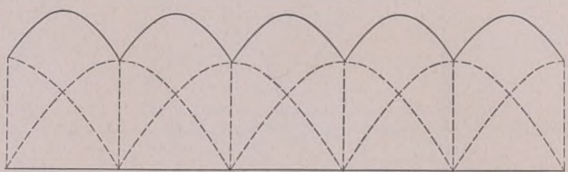


Fig. 62. Variation in Current with Two Coils at Right Angles.

which the dotted curves represent the electromotive forces generated by the two coils, and the full line the resulting E. M. F., which is the sum of the two at any given point. It is evident from inspection that the fluctuation in E. M. F. of the upper or combined curve is much less than either of the dotted curves produced by a single coil. In a similar manner it may be shown that a further increase in the number of coils, uniformly spaced, will cause less and less fluctuation, and by using 30 or more, a practically constant current may be obtained.

Alternating-Current Dynamos.

Alternating-current machines are commonly called *alternators.* They are only made to supply a current at constant potential.

The magnetic field is produced in three different ways, known as *separate* excitation, *composite* excitation, and *compensated* excitation.

In the first case the field coils of the alternator are supplied with a direct current from a separate machine or exciter. In the second case the field is made up of two separate coils, one supplied with a current from the exciter, and the other with a direct current taken from the alternator by means of a commutator attached to the armature shaft beside the collecting rings.

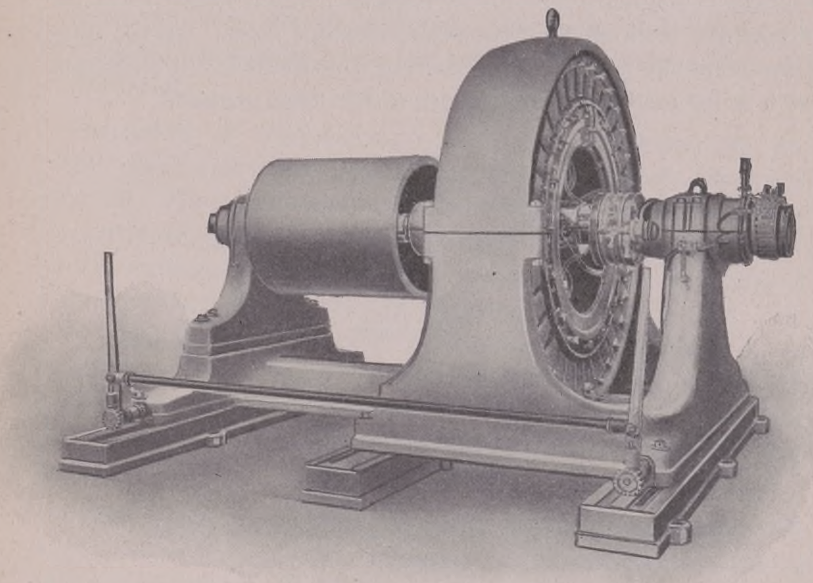


Fig. 63. Single Phase Alternator.

Either the whole or a part of the current generated by the alternator may be used in this way.

In compensated excitation it is so arranged that a portion of the current generated by the alternator may be used to vary the strength of current generated by the exciter. A single phase alternator is shown in Fig. 63.

Inductor Alternators.—In addition to the stationary and revolving field machines, there is another form called the *inductor* alternator, in which the field and armature coils are both stationary. The revolving part in this case, called the inductor, is of iron, made in the form of a gear wheel with very large teeth.

The shaft of the inductor extends through the center of the spool, upon which the field coil is wound, and the ends of the teeth pass close to the armature coils, which are wound on cores projecting from the inner circumference of the iron rim which forms the outer frame of the machine.

A current from the exciter is passed through the field coil; this produces a magnetic flux in the inductor, which issues from the ends of the teeth as they pass the armature coils. As the lines of force cut the conductors, a current is induced in the armature which is led to the external circuit in the usual manner.

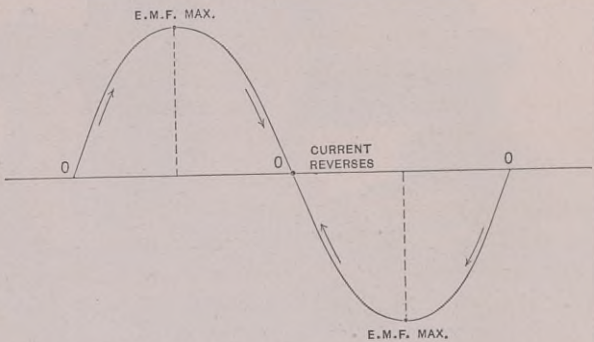


Fig. 64. E. M. F. Curve for One Cycle of Alternating Current.

Frequency.—It has already been stated that the change which takes place in the E. M. F., and resulting current, during a single revolution of a coil in the field between two poles of a magnet is called a cycle. This is shown graphically in Fig. 64, in which the curve represents the change in E. M. F. during one revolution of the armature, in the same manner as that described under pulsating currents.

The number of cycles per second is called the *frequency,* and is equal to the revolutions per second of the armature, times the number of pairs of poles which the dynamo has. We have seen that the changes in E. M. F. and current, represented in a cycle, take place while one of the conductors of the coil makes a complete revolution in the magnetic field, that is, while it passes from the north pole to the south pole, and back to the north pole again. From this it is evident that the frequency produced by a dynamo having two poles is equal to the number of revolutions of the armature per second. If there are two pairs of poles, the conductor will pass through these changes of field twice during each revolution and the frequency will be doubled, and so on for any number of pairs of poles.

Example.—An alternator having eight poles and making 900 revolutions per minute has a frequency of $(8 \div 2) \times (900 \div 60) = 60$ cycles.

Frequency of Alternations.—Alternating machines are generally made multipolar on account of the frequency required in practice. This commonly ranges from 25 to 60 cycles per second; the latter being used almost universally for miscellaneous work which includes lighting, and the former with occasionally 30 and 40 cycles for purely power work.

A machine with two poles must make 3,600 revolutions per minute to give a frequency of 60, and this speed is often attained in dynamos which are to be driven by steam turbines; if four poles are used the speed can be reduced one half. Alternators commonly have from 2 to 48 or more poles.

Phase.—Dynamos generating a current like that shown in Fig. 64 are called *single-phase* machines. If the armature be made up of two coils placed at right angles to each other, instead of the single coil which has been considered in the previous examples, it is evident that when the conductors of one coil are moving in planes parallel to the lines of force the other pair are cutting them at right angles; consequently the E. M. F. generated by one coil is at a maximum while that generated by the other is at zero. The two electromotive forces or currents generated in this case are shown graphically in Fig. 65. This is called a *two-phase* current.

An armature made up of three coils placed at angles of 120° from each other about the axis of rotation will produce a *three-phase* current. Currents of more than three phase are seldom used in practice owing to the complications which occur in wiring.

Single-phase currents give satisfactory results for lighting, but for power purposes polyphase currents are necessary for the best results.

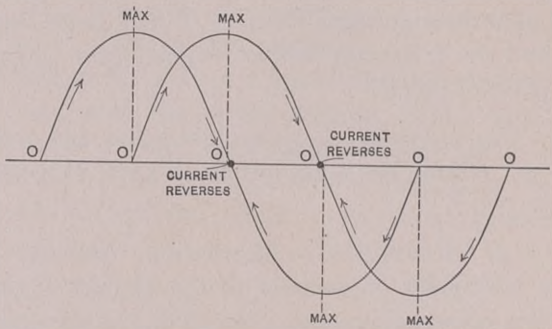


Fig. 65. Curves for Two-phase Current.

Transformers, Converters, Etc.

Transformers.—The voltage of an alternating current may be changed by passing it through a *transformer.* When the voltage is reduced it is called a *step-down* transformation, and when it is increased, a *step-up* transformation.

A transformer consists primarily of two distinct coils of wire insulated from each other and wound upon a laminated iron core.

In some makes they are arranged one within the other, but the more common method, especially in the case of larger sizes, is to place them side by side.

The coil which receives the current is called the *primary* coil, and that which delivers the transformed current is called the *secondary* coil. An alternator with revolving armature, produces an alternating E. M. F. by the cutting of a fixed magnetic field or flux by wires which move relatively to the field. In a transformer an alternating E. M. F. is produced in the secondary coil by the reversal of the magnetic flux in the iron core, these reversals being produced by the alternating current which is supplied to the primary coil. The relative voltages of the currents received and delivered by the transformer depend upon the number of turns of wire in the primary and secondary coils. All parts of a transformer are stationary.

Motor Generators and Rotary Converters.—An alternating current may be changed to a direct current or vice-versa, by means of either a *motor generator* or *rotary converter*. The former consists of a motor and dynamo mounted upon the same shaft. The current is received by the motor, which, in the first case, is

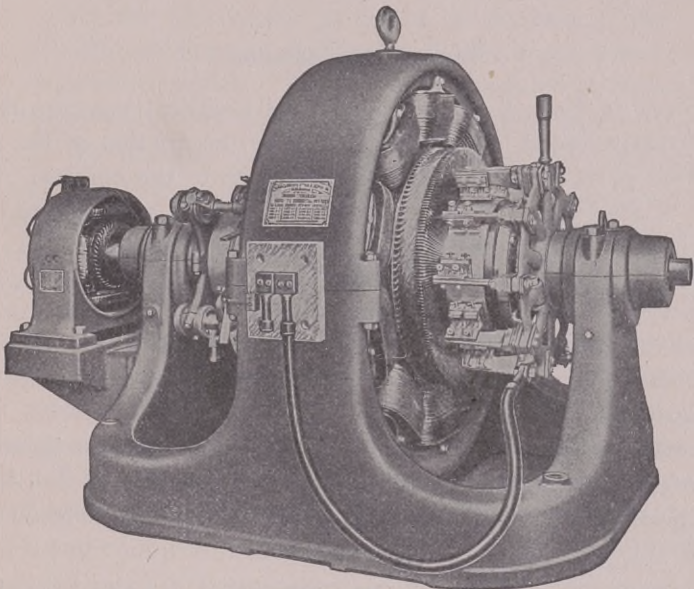


Fig. 66. Rotary Converter.

designed for an alternating current, and this in turn drives the dynamo which generates a direct current. In case it is desired to change a direct current to an alternating current the machines are reversed, that is, a direct-current motor and an alternating generator are used. The rotary converter is a machine having an armature, on one side of which is a set of collector rings for receiving or delivering an alternating current, and on the other side a commutator for delivering or receiving a direct current, the windings being common for both currents.

The rotary converter has some advantages in efficiency and cost over a motor-generator set, but requires so-called "intermediate" transformers and lacks the flexibility of voltage control which is found in the motor-generator. A rotary converter is shown in Fig. 66. In this case the commutator is at the left of the field coils and the collector rings at the right. These machines are usually provided with a small starting motor which is shown at the extreme right in the cut.

Practical Considerations.

Losses in Energy.—In operating an electrical machine there is a certain loss in energy due partly to the friction of the mechanical parts, and partly to the resistance to the current. The ratio of the amount of energy which a machine gives out to that which it receives is called the *commercial efficiency.* For example, if an input of 100 horse power of mechanical energy is given to a generator and only 90 horse power of electrical energy is delivered, the efficiency is $(90 \times 100) \div 100 = 90$ per cent. The efficiency of generators varies according to their size and the load carried.

Tests of a standard make show an efficiency of from 85 to 93 per cent for generators ranging from 5 to 200 Kw. at full load, and an efficiency of 82 to 85 per cent for the same machines at one half load.

Number of Units.—A dynamo with its connecting engine is called a *unit.* In an electric lighting plant the load is usually very light during the day and is at a maximum for a few hours only during the evening. For this reason it is very desirable, unless the power supplied is small, to have several units so arranged that as the load increases their power may be successively added as required. The relative size of the units is a matter upon which there is some difference in opinion. The best economy in operation is obtained where large machines are used during periods of heavy loads and those of small size during light loads.

While greater economy may be secured by making all the units of a different size, certain practical considerations may often lead to a different course.

It is the custom of many engineers to divide the total capacity into three units, each of such size that two of them, by being overworked not exceeding 30 per cent, can do the maximum work satisfactorily. This permits the withdrawal of one unit in case of accident or repairs, and besides, the three are interchangeable on the work. Their first cost is usually less, they adapt themselves better to the available space in the engine room, only one size of parts need be kept for repairs, and in case of accident the plant would not be crippled as would be the case if the units were of different size and the largest should break down at the time of heaviest loading. The size of the dynamo in connection with light loads, is not of so much importance as that of the engine, for its efficiency does not decrease so rapidly with underloading. Even at one third load the efficiency of some dynamos is but little less than that at full load; also small dynamos are made nearly as efficient as those of larger capacity, so that it is allowable to suit their size and number to the requirements of the engines.

Direct Coupling of Engines and Dynamos.—This has great advantages over other methods of connecting. It is simple, compact, produces no loss of efficiency due to belting or countershafting, and also does away with the noise of belt-driven machines. The economy in space is of much importance in the case of office and other city buildings. With a direct connection the dynamo must run at the same speed as the engine, and since the normal speed of a generator is usually much higher than that of an engine, the generator must run at a comparatively slow speed, and a high-speed engine must be used.

Running a dynamo at slow speed reduces its economy somewhat, but the advantages to be gained by direct coupling usually more than offset this, and in many cases it is a necessity on account of the available floor space. Belted dynamos are sometimes preferred in small plants where there is ample room. They are also better adapted to cases where it is desired to connect them with engines already installed. If a belted machine is to be used it is better to employ the slow-speed type as it runs cooler and with less liability of injuring the armature than those of higher speeds.

Power of Engine.—The size of engine required for driving a dynamo depends upon the efficiencies of both machines. For full loads, under ordinary conditions, we may assume an efficiency of 80 to 85 per cent for engines up to 100 horse power, and 85 to 90 per cent for larger sizes; and efficiencies of 85 to 90 per cent for generators up to 100 Kw. and 90 to 95 per cent for larger machines.

Example.—What must be the indicated horse power of an engine to drive a dynamo delivering 100 Kw.?

As the I. H. P. of the engine must always be greater than the Kw. rating of the dynamo, it is evident in this case that it must be over 100, and we can therefore assume an efficiency of 85 per cent. We have 100 Kw. = 100,000 watts = 100,000 ÷ 746 = 134 H. P. If the efficiency of the dynamo is 90 per cent, and its output of energy is to be 134 H. P., the input or *delivered horse power* of the engine must be 134 ÷ 0.90 = 149.

If the efficiency of the engine is 85 per cent, the I. H. P. will be 149 ÷ 0.85 = 175.

Putting this in the form of an equation we have,

$$\text{I. H. P. of engine} = \frac{\text{Kw.} \times 1{,}000}{746 \times A \times B}$$

in which

A = efficiency of engine.

B = efficiency of dynamo.

Taking the lower efficiencies as given above, we have, I. H. P. of engine = Kw. of dynamo × 1.75 for dynamos up to 100 Kw., and Kw. × 1.57 for larger sizes.

The dimensions of different types and makes of machines will vary somewhat, and in making an accurate layout where space is limited, exact dimensions should always be obtained from the makers of the machines to be used.

The approximate floor dimensions of direct-connected sets may be obtained by adding the width of the engine-type generator to that of the required size of belted engine as given in Chapter II. The total length, in most cases, will be the same as that of the engine, although in some instances it is slightly increased.

In arranging dynamos in place, space should always be left for the removal of the armatures.

Size of Generator.—For convenience in approximating the floor space required for generators of different types, tables are given for the following:

Crocker-Wheeler 250 Volt, Belted Type, Slow-speed Generators, the design of which is shown in Fig. 67.

Westinghouse 125 Volt, Engine-Type Generator (direct-connected) shown in the line drawing, Fig. 68.

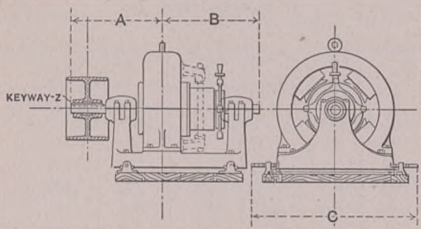


Fig. 67. Crocker Wheeler Belted Generator.

TABLE XXIV.

FLOOR SPACE FOR CROCKER-WHEELER SLOW-SPEED GENERATORS, BELTED TYPE.

Kw.	Revolutions per minute	A	B	C
		In.	In.	In.
9	950	$16\frac{1}{4}$	$17\frac{3}{4}$	$40\frac{1}{4}$
13	900	$18\frac{3}{4}$	$21\frac{1}{8}$	$42\frac{3}{4}$
18	875	$19\frac{1}{2}$	22	$46\frac{1}{4}$
$22\frac{1}{2}$	850	$21\frac{5}{8}$	$24\frac{3}{8}$	$48\frac{1}{4}$
30	800	$25\frac{5}{8}$	$28\frac{1}{4}$	$56\frac{3}{4}$
45	700	$30\frac{7}{8}$	$34\frac{3}{8}$	$61\frac{1}{2}$
65	625	$35\frac{1}{2}$	$38\frac{1}{4}$	75
100	650	$38\frac{3}{4}$	41	75
130	500	$45\frac{3}{4}$	$45\frac{1}{4}$	$115\frac{1}{2}$

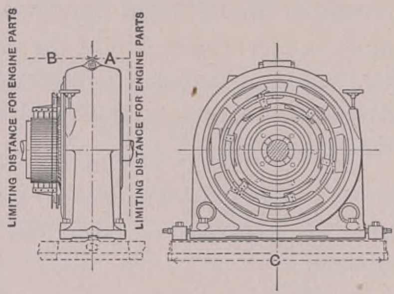


Fig. 68. Westinghouse Direct-connected Generator.

Table XXV.

Floor Space for Westinghouse Engine Type Generators, Direct Connected.

Kw.	Revolutions per minute	A	B	C
		In.	In.	In.
10	375 to 400	7	12	34
25	320 " 350	9½	18½	53½
50	275 " 300	10¼	21¾	63½
75	265 " 290	12½	26¾	70
100	250 " 275	12½	27¼	81½
150	200 " 225	15½	38	120
200	170 " 185	16	40	120
250	100 " 110	17	48	144

CHAPTER VII.

ELECTRIC MOTORS.

Distinction between Generators and Motors.—A generator converts mechanical energy into electrical energy. A motor serves to convert electrical energy into mechanical energy.

The generator and motor are similar in construction, but the operation of one is the reverse of the other. We have learned that when a conductor which forms part of a closed circuit moves so as to cut lines of magnetic force, a current of electricity passes through the conductor; this is the principle of the generator. On the other hand, if a current is passed through a conductor at right angles to lines of magnetic force, the conductor tends to move so as to cut them. This is the fundamental principle of the motor. There is essentially no difference between a motor and a generator. If a current is passed through the armature of a generator we have the conditions for a motor, and the armature will tend to rotate.

Motors for Driving Ventilating Fans.—There are many different types of motors in general use, but only those best adapted to the driving of ventilating fans and similar work will be considered to any extent. For the best results, fan motors should run at a comparatively slow speed, in order to avoid noise and vibration.

In many instances it is desirable to connect the motor directly to the fan shaft, in which case a lower continuous speed is called for than in almost any other class of work. Another desirable feature is the ability to vary the speed within reasonable limits, above and below the normal. These several requirements are satisfactorily fulfilled only in direct-current machines at the present time, although manufacturers are endeavoring to perfect devices for varying the speed of alternating current motors in a similar manner.

Where an alternating current only is available, high-speed belted motors must be used and special means taken to muffle the sound and prevent vibration.

Counter Electro-motive Force.—It has been shown in the discussion upon dynamos that when a conductor moves across lines of magnetic force, an E. M. F. is generated in the conductor. Now when the armature of a motor is caused to rotate, by passing a current through it, the very act of moving across the magnetic field generates an independent E. M. F. in the armature; in other words, the machine acts as a generator while running as a motor.

The E. M. F. thus generated is opposed to that applied at the brushes of the motor and is called the *counter* E. M. F. This is designated by the letter e in the following equations.

We have also learned that the E. M. F. generated by an armature rotating in a magnetic field, depends upon the speed, the number of conductors, and the strength of field. Therefore, if s is the speed of rotation, a the number of conductors on the surface of the armature, f the field strength, and K a constant, the counter E. M. F. will be represented by the equation $e = s\,a\,f\,K$.

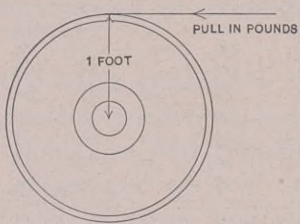


Fig. 69. Illustrating Torque.

Torque.—The torque of a motor is its tendency to rotate. It is commonly expressed in foot pounds, and is equal to the pull in pounds at a distance of 1 foot from the center of the shaft. (See Fig. 69.)

The work done per revolution is equal to the torque multiplied by the circumference of a circle whose radius is 1, or $W = T \times 2\,\Pi$ in which

W = work in foot-pounds per revolution.

T = torque.

$\Pi = 3.1416$.

The torque varies in any given armature directly as the product of the field strength and armature current. That is, if the field is kept constant, the torque will vary directly as the current, and if the current remains constant the torque will vary as the field.

Direct-Current Motors.

The windings of direct-current motors correspond to those of dynamos, the most common being the shunt field winding, and the compound field winding. Series wound motors are rarely used except for railway and heavy power work. Motors may be supplied with electrical power at a constant potential or with a constant current.

Speed of Motors.—In order to understand the factors which affect the speed of a motor it is necessary to go back to the fundamental equation

$$I = E \div R$$

in which I is the current which will flow through a conductor whose resistance is R, when the voltage or difference in potential between the ends of the conductor is E. This equation also applies to a motor when the armature is forcibly restrained from rotating, I being the current passing through the armature, E the E. M. F. applied at the brushes, and R the armature resistance.

As soon as the armature is allowed to rotate, a counter E. M. F. is set up, and the effective E. M. F. is reduced, being equal now to the applied E. M. F. less the counter E. M. F. Then for a motor whose armature is in motion, the equation becomes

$$I = (E - e) \div R$$

in which

$I =$ the armature current.
$E =$ the applied E. M. F.
$e =$ the counter E. M. F.
$R =$ the armature resistance.

It has already been shown that $e = s\ a\ f\ K$, and substituting this value in the above equation and solving for s we have

$$s = E \div a\ f\ K$$

which is the expression for speed and from which it is easy to see which factors must be changed to vary the speed of a motor under given conditions.

Shunt motors on constant potential circuits are best adapted to fan work; they are self-regulating and run at a sufficiently constant speed for all practical purposes. As the field strength of a shunt motor on a constant potential circuit is constant, the torque will vary only as the strength of the armature current.

The speed of a shunt motor on a constant potential circuit is practically constant for all loads. This is evident from the equation

$$s = E \div a f K$$

in which all of the factors in the second member are constant under these conditions, and therefore the speed must be constant. As a matter of fact, the speed will be reduced slightly as the load, or torque, increases. This is because an increase in torque calls for a corresponding increase in the current (the field being constant), and this can only occur by reducing the counter E. M. F. When the load is increased, the speed drops slightly, and this reduces the counter E. M. F., allowing a larger current to flow through the armature and thus bringing up the torque to meet the added requirements. This change of speed, however, is so small that for all practical purposes the motor may be considered to have a constant speed for all loads within its capacity.

Starting Resistance.—If the armature of a motor is restrained from rotating, the current passing through it will be excessively large because no counter E. M. F. is generated. On this account it is necessary when starting up a motor to first throw a large resistance into the armature circuit, and then gradually reduce it as the motor comes up to speed. This is accomplished by means of a starting rheostat, a common form of which is shown in diagram in Fig. 70.

Starting Rheostat.—This consists of a number of resistance coils enclosed in a case, and so arranged that by moving a lever a greater or lesser number can be thrown into the circuit, thus decreasing or increasing the current as desired. The starting position in Fig. 70 is with the lever *S* against the pin *A*, in which case the armature circuit is open. By moving the lever toward the right the circuit is closed through the resistance coils, *a, a, a,* and by moving it still further toward the right from point to point, more coils are cut out and the speed correspondingly increased. When the lever is in the vertical position shown in the cut, the resistance is entirely cut out, and the lever is held in place by a small electro-magnet, the coils of which are in series with the field. When the main switch is thrown, and the current cut off, the magnet ceases to act and the lever is thrown back

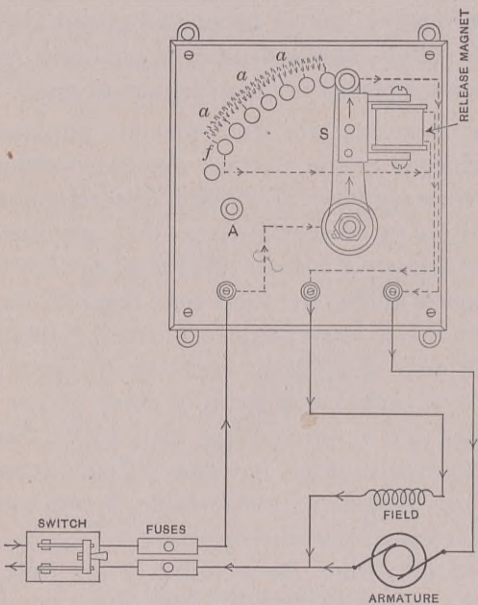


Fig. 70. Motor Starter Diagram showing Circuit Connections.

automatically by means of a spring to the starting point against the pin. An arrangement of this kind is called a *no-voltage* release, and is of special value in case the current supplying the motor is interrupted and then restored, as otherwise the fuses would be blown out and possibly further damage done.

The starting rheostats of large motors are often equipped with *overload releases,* which open the supply lines in a similar manner when the motor becomes greatly overloaded.

Speed Regulation.

In the case of ventilating fans of any considerable size, it is often desirable to vary the speed somewhat, and for this reason, fan motors are usually equipped with speed regulating devices. These commonly operate in one of three ways, as follows: By varying the E. M. F. applied at the brushes; by varying the field strength, and by changing the number of armature conductors. Of these the first two are the most common and are often used in combination to get a greater range of speed, especially in the case of large motors, say 20 horse power and above. A variation of the E. M. F. at the brushes is obtained by the use of a variable resistance placed in the armature circuit.

Regulating Rheostats are used for this purpose. These are similar in principle to the starting rheostat, although somewhat different in construction. A starting rheostat, however, should never be used for speed regulation, as they are usually very compact and have a relatively small surface exposed to the air. They do not heat much during the short time required for starting, but if allowed to carry the armature current constantly they are liable to burn out. Standard regulating rheostats for armature resistance give a variation in speed of about 50 per cent, and are commonly used for motors of less than 15 or 20 horse power. They have the disadvantage, however, of poor economy, because the energy lost in heat is considerable, being equal to I^2r, in which r is the resistance of the rheostat.

The method of wiring for a shunt motor with a regulating rheostat in the armature circuit is the same as that shown in Fig. 70. The regulating rheostat in this case takes the place of the usual starting rheostat.

Regulating by Varying Strength of Field.—Regulation by this means is generally accomplished by placing a regulating rheostat in the field circuit. In this way the current passing through the field coils may be changed, and the field strength varied as desired.

The coils for armature and field resistance are usually combined in the same rheostat, as shown in Fig. 71. Moving the lever toward the right increases the speed of the motor by first cutting out the resistance in the armature circuit. A further movement of the lever throws an increasing resistance into the field circuit, thus weakening it and causing the speed to increase still more.

A speed variation of 100 per cent is commonly obtained with rheostats of this kind. Another method of changing the field strength is by having part of the field windings of German silver, and so arranged that they may be cut in or out as desired. This constitutes a part of the motor construction and is not in general use.

Speed regulation by changing the number of armature conductors is not used on motors employed for ventilating work.

Too great an increase in speed by weakening the field will cause sparking at the brushes, so that this method of regulation is limited to a certain extent.

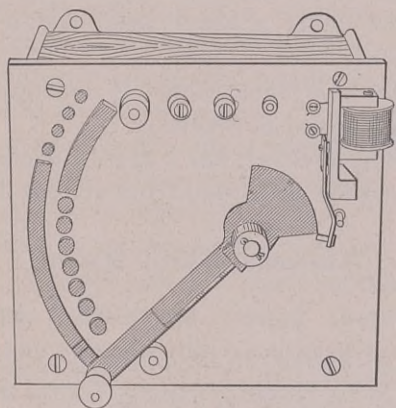


Fig. 71. Regulating Rheostat.

Mechanical Regulation.—The continuous use of rheostats for speed regulation should be avoided when possible, it being better in the case of enclosed fans of the blower type to use throttling dampers in the airways, rather than depend entirely upon cutting down the speed. It is desirable at times, however, to reduce the capacity of a fan temporarily, as for an evening lecture or entertainment in the hall of a school building. In cases of this kind the speed may be reduced for two or three hours by the use of a rheostat without a serious waste of energy.

Shunt Motors are not commonly used on constant current circuits. They cannot be made self-regulating, and so require some form of mechanical governor.

Another objection is the usually high potential of the circuit, which may be a source of considerable danger in some cases.

Series Motors.—These motors are principally employed in electric railway work where they are commonly run on a 500-volt circuit. They are also used for operating hoists and mining machinery where a constant speed is not necessary.

A starting rheostat is required the same as with a shunt motor, when used on a constant potential circuit.

Compound Motors.—There are various forms of compound motors, each adapted to some special requirement.

The *cumulative compound* motor is used in cases where it is frequently started under a heavy load, and where a constant speed is not required.

The *differential compound motor* is employed where a very close regulation of speed is necessary.

The shunt motor, however, has a speed sufficiently uniform for most purposes, and the compound types are but little used.

Alternating-Current Motors.

Alternating-current Motors are divided into two general classes known as *synchronous* and *induction* motors. Both kinds are in common use, but the induction motor, having properties which adapt it to a wider field of application, is more generally employed in ventilating work, especially for the smaller sizes.

Synchronous Motors.—An alternating-current generator may be used as a synchronous motor without change in construction, and the same machine is often used indifferently for either purpose. Composite field winding, however, is never employed on generators designed to be run as motors.

Synchronous motors are made to operate on either single-phase or polyphase systems, although the former cases are exceedingly rare, and derive their name from the fact that they must run in *synchronism* with the alternator supplying the current. This means they must have the same frequency. The speed of the motor depends upon that of the generator, but will not be the same unless each has the same number of poles. The speed at which a synchronous motor will run when connected to a generator supplying current at a frequency f is

$$S = \frac{2 \times f \times 60}{p}$$

in which

S = speed of motor in revolutions per minute.

f = frequency of the alternator supplying the current.

p = number of poles on the motor field.

This will be made plain by reference to the paragraph on frequency in the previous chapter.

Synchronous motors will run at a constant speed under all loads; they are somewhat cheaper to construct than induction motors, especially at low speeds, and usually have a higher efficiency. On the other hand, they require a direct exciting current from an outside source, have a small starting torque, and have no speed variation, as the frequency must always be the same as that of the generator supplying the current.

They require more skilled attendance, and are more generally used in the larger sizes and where it is not necessary to start and stop them frequently.

Starting a Synchronous Motor.—In starting up a single-phase motor of this type it is necessary to bring it up to speed from some outside source before throwing on the load.

Polyphase machines are self-starting when under no belt load, and may therefore be run light up to speed, and the load then thrown on gradually by means of a friction clutch. An objection to this is the fact that an excessive current is required at the start, which is liable to dim the lights, when the motor is used on a lighting circuit. For this reason the larger sizes are sometimes provided with a small induction, or direct-current motor for first bringing them up to speed; the starting motor is then thrown out of gear, and the load gradually thrown on as before.

When the current required by the motor is small, the self-starting type is generally employed.

An *auto-starter* or *compensator* is often used in connection with this type of motor. This is an arrangement of transformers, by means of which the voltage applied at the armature terminals may be reduced when starting, and then brought up quickly to the full voltage when the motor is up to speed.

Induction motors have no brushes or collecting rings like the synchronous motor, but consist of two principal parts made up of thin layers of iron, to which are attached specially formed coils or bars of copper. The outer or surrounding ring is called the

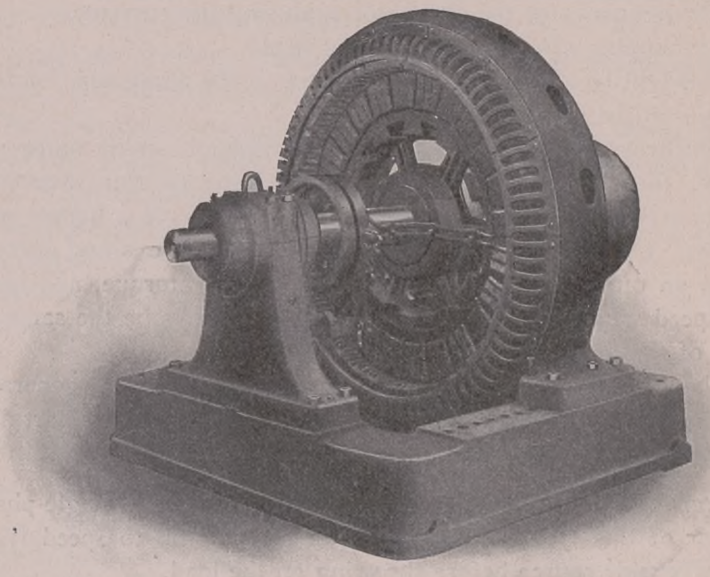
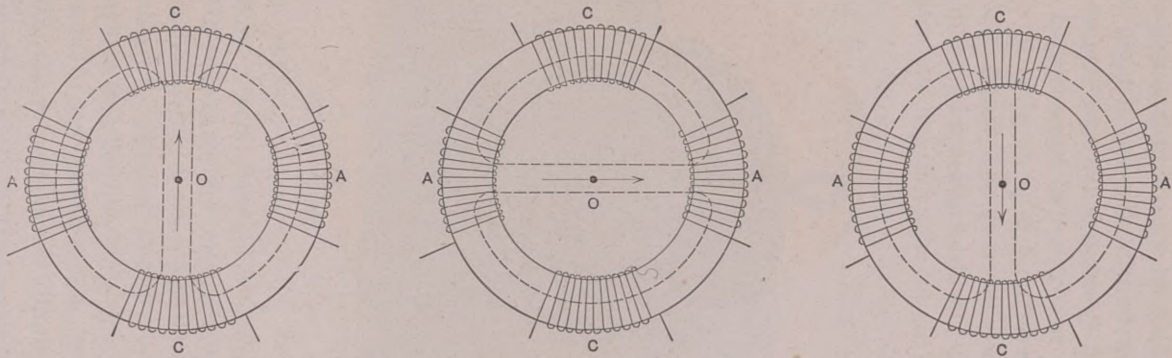


Fig. 72. Synchronous Motor.

primary member or *stator,* and sometimes the field. It is usually stationary, and its coils receive an alternating current from the circuit with which the motor is connected. The secondary member, called the *rotor* or armature, is in the form of a drum or core, and rotates inside of the stator. This part of the motor is not connected with the outside circuit.

Induction motors are made to run on both single-phase and polyphase circuits.



Figs. 73, 74 and 75. Illustrating Principles of Rotating Field of Polyphase Induction Motors.

Generation of a Rotating Field.—For the purpose of simplicity let us consider the stator of a two-phase motor to consist of an iron ring with two pairs of coils wound upon it, as shown in Fig. 73. Let coils *A A* be connected with one of the circuits of a two-phase system, and coils *C C* be connected with the other circuit of the same system.

At the instant when the current through *A A* is at a maximum, that through *C C* will be at a minimum, or zero. Let the direction of the current passing through the coils *A A* be such

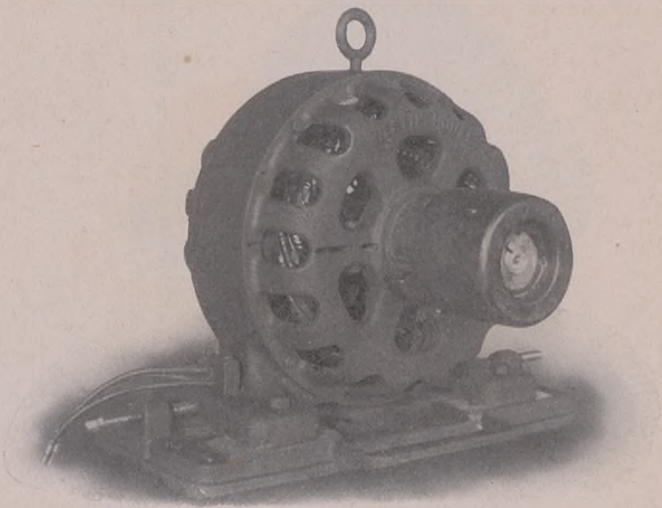


Fig. 76. Induction Motor.

as to produce a magnetic field, with lines of force following the path shown by the dotted lines, and having a direction indicated by the arrow. If we look at the conditions an instant later, when the current through *C C* has reached a maximum, and that through *A A* has become zero, we shall find that the lines of force now take the direction shown in Fig. 74. Following this action through another step until the current in the coils *A A* is again at a maximum, but in the opposite direction, the lines of force will follow the same path as in Fig. 73, but the flow of magnetic flux will be reversed, as indicated in Fig. 75.

Thus we see that the action of the two currents flowing through the two sets of coils is such as to produce what is called a rotating field. That is, the path of the magnetic flux across the space enclosed by the stator is constantly changing its angle, or in other words, rotates about the center *O*. In practice there are a large number of coils grouped in as many sets as there are phases in the current, and they are usually held in slots inside of the stator ring instead of being wound upon it as shown in the diagram.

Westinghouse Induction Motor.—Fig. 76 shows a Westinghouse motor of the induction type designed either for two or

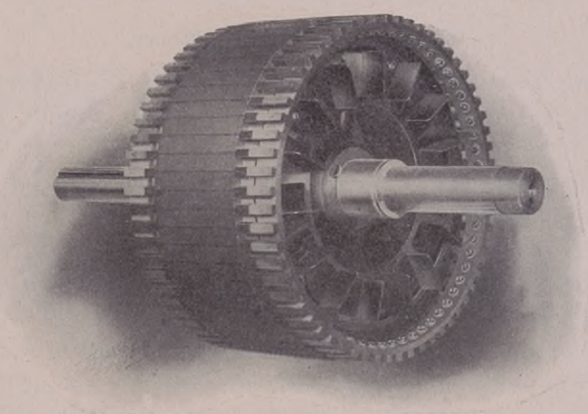


Fig. 77. Rotor of Induction Motor.

three-phase alternating current circuits. The rotor is shown in position within the stator. This particular form is known as the "squirrel cage" type, and consists of a drum or core made up of a large number of sheet-iron disks held in place by a spider, and mounted upon a shaft. Parallel copper bars are placed in slots around the outer surface of the core, and the ends soldered, or otherwise fastened, to heavy copper rings as shown in Fig. 77.

Action of an Induction Motor.—This may best be explained by assuming the rotor to be held in a stationary position, while an alternating current is passed through the field coils. The result of this will be the generation of a rotating flux or field, which will cut the conductors of the rotor and induce electric currents in them. These currents will in turn produce a magnetic field with lines of force, which, if the rotor is released, will tend to set themselves parallel with those of the field. As the field rotates, the induced flux in the rotor also rotates, and as the lines of force in the field and those induced in the rotor are always at an angle with each other, the rotor will revolve in a constant effort to catch up with the rotating field and place its lines of force in parallel.

There are various forms of construction used for both field and armature, and other conditions enter into the actual working of the motor, but the above description serves to illustrate the principles upon which this type of machine operates.

Starting an Induction Motor.

Starting Two-phase and Three-phase Motors.—Induction motors designed for two-phase and three-phase circuits are self-starting under load, but unless some special provision is made, depending upon the type of rotor, the current passing through the motor in starting will be excessively great.

In the case of squirrel cage rotors it is customary, except in the smaller sizes, to use a compensator similar to that described for synchronous motors. This reduces the armature voltage at the start to about one half that of the circuit, and as soon as the motor is up to speed a switch is thrown which cuts out the transformer in the compensator, and the current is then delivered at its full voltage.

Another common form of rotor has a special winding of insulated wire instead of the copper bars previously described. The terminals of this winding are connected to a starting resistance inside of the rotor. When the motor is up to speed, this resistance is short-circuited by means of a sliding rod passing out through the hollow shaft of the rotor. In the smaller sizes this rod terminates in a small knob or button, by means of which the rod may be operated by hand. Larger sizes usually have a lever attachment instead.

In other forms the arrangement is such that an external resistance can be thrown into the rotor coils when starting, and cut out after the motor has reached its normal speed.

Starting Single-phase Motors.—Single-phase induction motors are not self-starting, but will run continuously when once brought up to speed. In very small sizes this may be done by giving the belt a vigorous pull when starting up the motor.

Larger sizes require special devices to make them self-starting. In some cases the current is split, and the motor acts as a two-phase machine at the start. When the speed reaches a certain point, this device is automatically cut out, and the motor then continues to run on a single-phase current.

There are other methods employed which vary somewhat from the above, but by means of which practically the same results are obtained.

Speed Regulation.

An alternating-current motor of the induction type is a constant field machine, and therefore tends to run at a constant speed. A variable speed may be obtained either by changing the primary voltage of the motor or by introducing a resistance into the secondary circuit.

Both of these methods may be compared with the regulation of a direct-current, constant-field machine, operated from a constant potential circuit, in which the changes in speed are obtained by introducing a variable resistance in series with the armature circuit.

When the speed variation is obtained by changing the primary voltage of the motor, the loss in energy occurs in the secondary or armature itself.

With the other method, the resistance is placed in the secondary or armature circuit, outside of the motor, and the heat which is generated is more easily disposed of. While induction motors are commonly used for running elevators, where the reduction of speed is for short intervals, they are not adapted to ventilating work, where the requirements of speed regulation are much more severe. When used for this purpose they should be belted, and any necessary variation in the speed of the fan should be obtained by the use of stepped pulleys rather than by regulating the speed of the motor.

Motor Connections.

Direct-Current System.—The connections for a direct-current, shunt-wound motor are very simple, and have been shown in Fig. 70.

The motor should be protected by safety fuses or cut-outs placed in the mains outside of the switch as indicated.

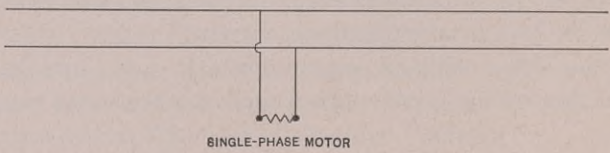


Fig. 78. Single-phase Two-wire System.

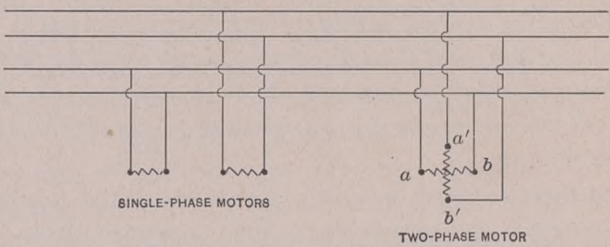


Fig. 79. Two-Phase Four-wire System.

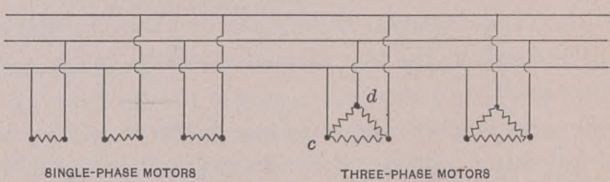


Fig. 80. Three-phase Three-wire System.

The switch is necessary for entirely disconnecting the motor when not in use, and the cut-out for protection against excessive currents due to accidents or careless handling when starting. Both the switch and rheostat should be located within sight of the motor. The direction of rotation can be changed either by reversing the connections at the brushes, or by reversing the current through the field.

Alternating-Current System.—There are various systems of wiring used for the transmission of alternating currents, the most common being the single-phase two-wire system, the two-phase four-wire system, and the three-phase three-wire system.

Figs. 78, 79 and 80 show the general method of making motor connections with these three systems.

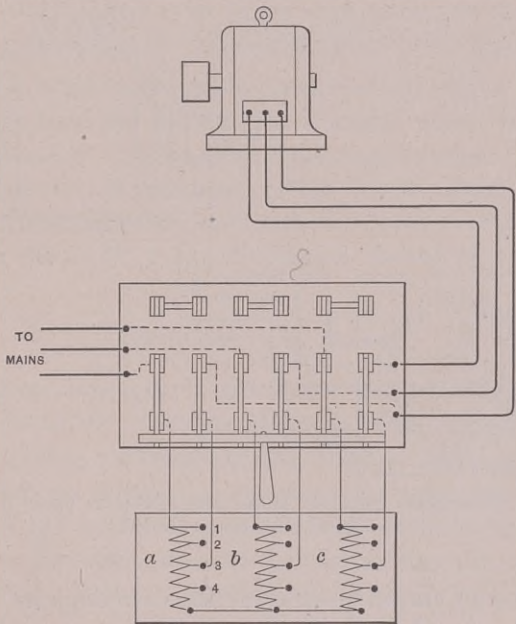


Fig. 81. Three-phase Induction Motor with Compensator Motor Starter.

A single-phase motor can be run from either of these, and the direction of rotation is reversed by reversing the connections at the binding posts.

The direction of rotation of a two-phase motor is reversed by reversing the connections, that is, by changing connections *a* and *b*, or a^1 and b^1 in Fig. 79.

A three-phase motor is reversed by interchanging any two of the three connections, as by reversing *c* and *d*, in Fig. 80.

Compensator Connections for a three-phase induction motor are shown in Fig. 81. When the switch is in the lower or starting position as indicated, a transformer coil is in series with each wire of the system leading to the motor; and the applied voltage is correspondingly cut down. After the motor reaches its rated speed, the switch is thrown to the upper or running position, and the stator or primary terminals are connected directly to the line.

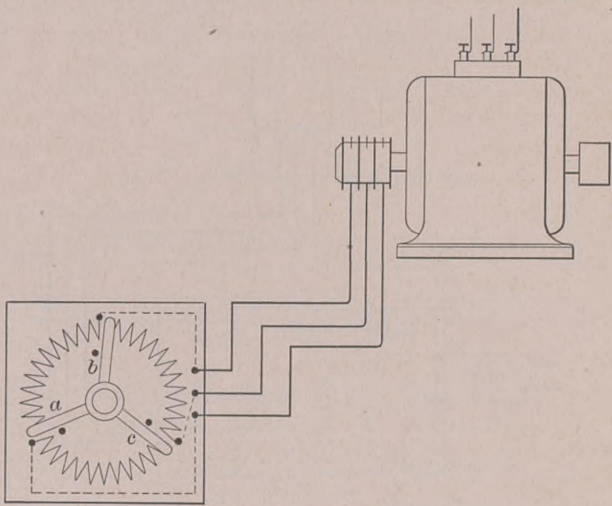


Fig. 82. Three-phase Induction Motor with Resistance Speed Regulator Connected with Rotor Circuit.

Wiring for a Controller.—Fig. 82 shows in diagram the method of inserting a variable resistance for speed regulation in the rotor circuit of a three-phase motor. The rotor winding for each phase is brought out to a collector ring on the shaft, and the current is taken off by means of contact brushes the same as from a generator. The resistance is provided in three sets, one for the lead from each brush, and each set is sub-divided so that it can be gradually cut out of the circuit as the speed of the motor increases.

The arms *a, b* and *c* in Fig. 82 are in electrical contact at the center, and the resistance is varied by turning the handle or knob toward the right or left.

Frequently the controller is so arranged that the first motion of the handle closes the supply lines, and subsequent movements vary the resistances in the rotor circuits, thus performing the function both of a supply switch and speed controller.

Efficiency of Motors.

The commercial efficiency of small motors ranges from 50 per cent to 75 per cent. Motors from 3 to 10 horse power have efficiencies which range from 75 per cent to 80 per cent. Larger motors have efficiencies in the neighborhood of 90 per cent.

Example.—What indicated horse power of engine will be required to generate the current for a motor which is to deliver 100 horse power? Assume efficiencies as follows: Engine 85 per cent, dynamo 90 per cent, motor 90 per cent. The total efficiency of the plant is $0.85 \times 0.90 \times 0.90 = 68.8$ per cent, from which the I. H. P. of the engine should be $100/0.688 = 145 +$.

Conditions to be Noted.

Specifications.—In specifying a motor, one of ample size should always be called for. It should be provided with the maker's name plate, giving the rated current, voltage, speed and capacity. The manufacturer should also guarantee the following: That the machine will not heat in any part of its windings to more than 45° C. above the temperature of the surrounding air, after a continuous run of six hours' duration, under rated load conditions; also that it will carry 25 per cent overload for two hours, and momentary overloads of 50 per cent, without excessive heating or sparking.

The current from which the motor is to be supplied should be fully described; the voltage should be given, and if alternating, the phase and frequency should be stated.

Foundations.—It is of great importance to have the motor mounted upon a solid foundation, otherwise the vibration will cause sparking at the brushes and also prove objectionable on account of the noise produced, especially in buildings like schools, churches, etc.

Small motors may be supported in a variety of ways depending upon local conditions. They are often placed upon a shelf or bracket securely bolted to a brick wall, or in other cases hung from the roof construction of a building when used in connection with attic ventilating fans.

The larger sizes, such as are employed for driving blowers and exhausters, are generally placed upon solid brick or concrete foundations. If bricks are used they should be hard burned, and laid in a good quality of cement mortar; a substantial wooden frame should be placed over the brickwork to form an even support for the base of the motor to rest upon. If the machine is of the belt-driven type, it must be provided with a sliding bedplate, having holding-down bolts and tightening screws for aligning and adjusting the belt.

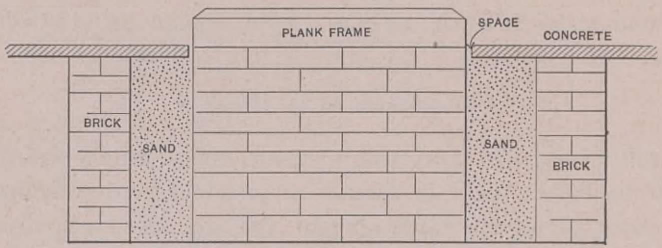


Fig. 83. Sound Deadening Foundation for Large Motors.

The smaller sizes of direct-connected motors are usually bolted to the iron framework of the fan casing, while those of larger size are mounted upon a separate brick foundation and connected to the fan shaft by means of a flexible coupling.

Sound Insulation.—When it is necessary to reduce the vibration to a minimum, a sound deadener, made up of several layers of hair felt between two sheets of lead may be placed between the base of the motor and the foundation, before drawing down the anchor bolts.

In the case of small motors which are placed on brackets or other similar supports, thick rubber washers may be substituted for the felt. Still further insulation may be procured by covering the motor with a wooden box lined with felt and asbestos paper, care being taken to provide suitable openings for air circulation.

Another very satisfactory arrangement is to build an 8-inch brick wall around the central foundation about 8 inches distant, and pack the space between them with moist sand, as shown in Fig. 83.

Care and Management of Motors.

The first step in the proper care and management of any piece of mechanism is a thorough understanding of its construction, and of the general principles upon which it operates. Therefore, the engineer in charge of a plant containing electric motors should familiarize himself with the particular makes under his care, by obtaining from the manufacturers cuts or prints showing the interior construction and details of the more important parts.

Essential Points.—The principal points to be borne in mind in the care of a motor are cleanliness, lubrication, and proper adjustment of the brushes. A cotton cloth should be used for cleaning, rather than waste, as the threads of the latter are apt to catch upon projecting parts around the brushes and commutator. All oil cups and reservoirs should be regularly filled and oiling rings kept in working order. The commutator should not be oiled, only wiped with a clean cloth moistened with a little sperm oil or vaseline.

In case of overloading or a rough commutator, more lubrication may be permitted, but if this is done, both brushes and commutator should be cleaned frequently.

Care of Commutator.—The commutator of a motor which is well made and well cared for will soon acquire a dark, polished surface. Sandpaper should be used sparingly, and only when the commutator becomes rough by reason of sparking or the accumulation of dirt. If the brushes press too heavily, the surface will become scored; if too lightly, there will be a vibration causing them to jump. Sparking causes the edges of the commutator bars to be burned away.

Care should be taken that no waste or pieces of wire adhere to the commutator, and that no dirt or copper dust has lodged between the bars; if this is found to be the case it should be removed by means of a stiff brush.

Care of New Machines.—A new machine, or one that has been changed in any way, should be carefully watched for a time after being put in operation. If possible, it should be run for an hour or two without a load, or for a longer period if it is a large one. Sometimes little flecks of copper collect under the brushes in the case of a new machine. Their presence may be detected by the appearance of a small, steady, green spark under the heel of the brush or by deep pits at the edge of the segments. These may be removed by raising the brush and picking off the copper with the point of a penknife; care being taken, however, to always turn off the current before the brushes are raised.

Fitting New Brushes.—New brushes may be fitted to the commutator by passing a strip of No. 2 sandpaper beneath the brush and drawing it back and forth, putting considerable tension on the spring. After the brushes are worked down to a good bearing a strip of fine sandpaper, No. 00, should be substituted for the coarse and the operation repeated until the brushes present a smooth and accurately curved surface to the commutator.

Sparkless running is of the greatest importance; if sparking occurs, rock the brushes backward and forward until a position is found where it ceases.

General Directions.—Touch the bearings and field coils occasionally to see if they are running cool. To determine if the armature is becoming hot, place the hand in the current of air thrown out by centrifugal force.

All tools or pieces of iron or steel should be kept away from the machine while running, as they are liable to be drawn in by the magnetism. For this reason copper or brass oil cans should always be used around a motor.

After a machine is stopped, it should be cleaned of all dirt, dust and superfluous oil, particular attention being paid to the commutator and brushes.

A motor can be much more readily cleaned after a run, when it is still warm, than after it has become cool.

Never allow the body to form part of a circuit. While handling a conductor, a second contact may be made accidentally through the feet, hands, knees, or other part of the body, in some peculiar and unexpected manner. For example, men have been killed because they touched a "live" wire while standing or sitting upon a conducting body.

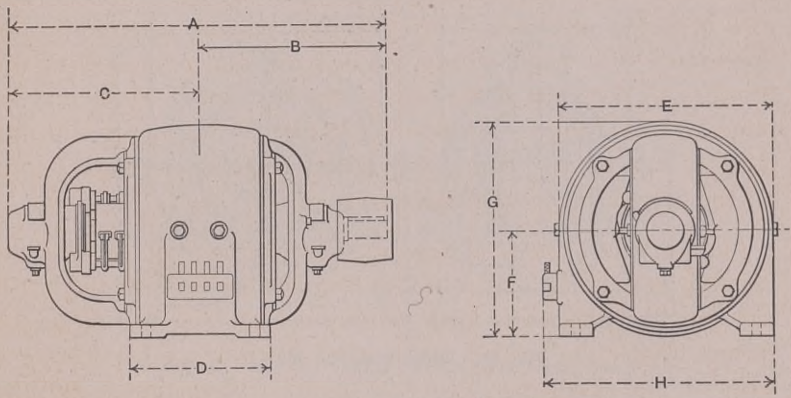


Fig. 84. Small Motors Suitable for Driving Fans.

TABLE XXVI.

D. C. SHUNT WOUND SLOW AND MODERATE SPEED BELTED MOTORS.

Horse power	Speed, revolutions per minute 110 V.	115 V.	125 V.	220 V.	230 V.	250 V.	500 V.	Weight	A	B	C	D	E	F	G	H
$\frac{1}{4}$	1800	1850	1950	1800	1850	1950	2000	55	$15\frac{1}{3}$	$7\frac{1}{16}$	$8\frac{1}{16}$	8	$8\frac{7}{8}$	$4\frac{1}{2}$	$8\frac{15}{16}$	$11\frac{1}{4}$
$\frac{1}{2}$	1600	1650	1750	1600	1650	1750	1800	80	17	8	9	9	$10\frac{1}{4}$	$5\frac{1}{4}$	$10\frac{3}{8}$	$12\frac{9}{16}$
$\frac{3}{4}$	1425	1475	1550	1425	1475	1550	1600	95	$18\frac{3}{8}$	$8\frac{15}{16}$	$9\frac{7}{16}$	9	$10\frac{3}{8}$	$5\frac{1}{4}$	$10\frac{7}{16}$	$12\frac{9}{16}$
1	1240	1275	1350	1240	1275	1350	1400	130	$20\frac{1}{2}$	$10\frac{1}{16}$	$10\frac{7}{16}$	$9\frac{3}{4}$	12	$6\frac{1}{4}$	$12\frac{1}{4}$	$13\frac{7}{8}$
2 3	1060 1600	1100 1650	1175 1750	1060 1600	1100 1650	1175 1750	1200 1800	240	$24\frac{7}{8}$	$12\frac{1}{2}$	$12\frac{3}{8}$	11	$14\frac{1}{8}$	$7\frac{1}{4}$	$14\frac{5}{16}$	17
3 5	1060 1600	1100 1650	1175 1750	1060 1600	1100 1650	1175 1750	1200 1800	380	$28\frac{11}{16}$	$14\frac{1}{4}$	$14\frac{7}{16}$	$12\frac{1}{2}$	$16\frac{1}{2}$	$8\frac{1}{2}$	$16\frac{3}{4}$	$19\frac{11}{16}$
5 $7\frac{1}{2}$	1060 1475	1100 1525	1175 1625	1060 1475	1100 1525	1175 1625	1200 1650	540	$33\frac{13}{16}$	$16\frac{13}{16}$	17	$12\frac{1}{2}$	$18\frac{5}{8}$	$9\frac{1}{2}$	$18\frac{13}{16}$	$20\frac{13}{16}$
$7\frac{1}{2}$ 10	800 1220	825 1250	875 1310	800 1220	825 1250	875 1310	1000 1350	725	$36\frac{15}{16}$	$17\frac{13}{16}$	$19\frac{1}{8}$	$14\frac{1}{2}$	$20\frac{3}{4}$	11	$21\frac{3}{8}$	$23\frac{1}{4}$
10 15	635 975	650 1000	685 1050	635 975	650 1000	685 1050	800 1200	900	$40\frac{1}{4}$	$19\frac{3}{8}$	$20\frac{7}{8}$	$15\frac{1}{2}$	23	12	$23\frac{1}{2}$	$25\frac{3}{16}$
15 20	610 900	625 925	660 975	610 900	625 925	660 975	750 1125	1300	$44\frac{3}{4}$	$21\frac{1}{16}$	$23\frac{11}{16}$	$16\frac{1}{2}$	26	$13\frac{1}{2}$	$26\frac{1}{2}$	$28\frac{3}{16}$

Rubber gloves or rubber shoes, or both, should be used in handling circuits of over 500 volts. The safest plan is not to touch any conductor while the current is on; and it should be remembered that the current may be present when not expected, owing to an accidental contact with some other wire or to a change of connections. Tools with insulated handles, or a dry stick of wood, should be used instead of the bare hand.

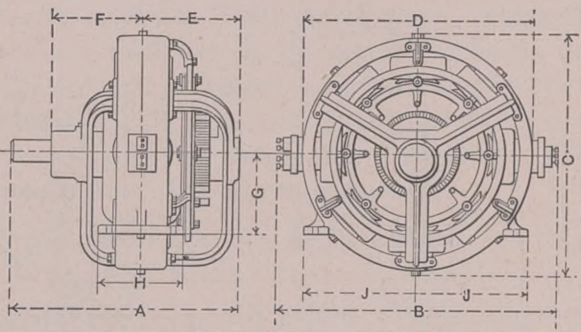


Fig. 85. Large Size Fan Motor.

Table XXVII.

Dimensions of Motors Shown in Fig. 85 Adapted for Driving Large Fans.

Size number	A	B	C	D	E	F	G	H	J
1 -100	$21\frac{1}{2}$	$31\frac{3}{8}$	$26\frac{1}{2}$	$25\frac{1}{2}$	10	8	9	6	$12\frac{3}{4}$
$1\frac{1}{2}$-100	22	$31\frac{3}{8}$	$26\frac{1}{2}$	$25\frac{1}{2}$	$10\frac{1}{4}$	$8\frac{1}{4}$	9	6	$12\frac{3}{4}$
2 -100	$28\frac{21}{32}$	$36\frac{5}{8}$	$31\frac{3}{4}$	$30\frac{3}{4}$	$12\frac{3}{8}$	$10\frac{15}{16}$	$10\frac{1}{2}$	7	15
3 -100	$29\frac{1}{2}$	$36\frac{5}{8}$	$32\frac{1}{4}$	$31\frac{1}{4}$	$12\frac{7}{16}$	11	$10\frac{1}{2}$	7	15
4 -100	$30\frac{15}{16}$	$40\frac{5}{8}$	$35\frac{3}{4}$	$34\frac{1}{2}$	$12\frac{3}{4}$	$11\frac{1}{8}$	$11\frac{3}{4}$	$9\frac{1}{2}$	$16\frac{3}{4}$
5 -100	$33\frac{1}{4}$	$41\frac{7}{8}$	$36\frac{1}{2}$	$35\frac{1}{4}$	$13\frac{5}{8}$	12	12	$11\frac{1}{4}$	17
6 -100	$36\frac{1}{4}$	$43\frac{5}{8}$	39	$37\frac{1}{2}$	$14\frac{1}{8}$	$14\frac{1}{8}$	$12\frac{3}{4}$	12	18

The rule to use *only one hand* when handling dangerous electrical conductors or apparatus is a very good one, because it avoids the chance, which is very great, of making contacts with both hands and getting the current through the body.

Methods of Stopping Motors.—The method of starting up motors of different types has already been described. The same general directions apply to stopping them, except in the reverse order.

Constant-potential motors are stopped by simply opening the switch in the connections with the circuit, and allowing the handle of the rheostat to throw back to the starting point automatically. If the rheostat is not furnished with an automatic release, this must be done by hand.

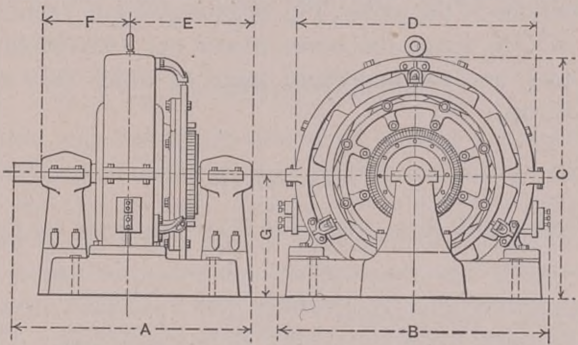


Fig. 86. Another Design of Motor for Large Fans.

Table XXVIII.

Dimensions of Motors (Fig. 86) Adapted for Driving Large Fans.

Size number	A	B	C	D	E	F	G
8 -100	$49\frac{1}{4}$	47	$41\frac{1}{2}$	41	$22\frac{3}{4}$	$18\frac{1}{2}$	21
10 -100	$51\frac{11}{16}$	49	$44\frac{3}{4}$	$43\frac{1}{2}$	$23\frac{1}{4}$	$18\frac{7}{8}$	23
$12\frac{1}{2}$-100	$52\frac{5}{8}$	52	$45\frac{3}{4}$	$43\frac{1}{2}$	$24\frac{3}{4}$	$19\frac{7}{8}$	24
15 -100	53	$56\frac{1}{4}$	$50\frac{1}{8}$	$49\frac{3}{4}$	$25\frac{1}{2}$	$19\frac{7}{16}$	$25\frac{1}{4}$
24 -100	$64\frac{1}{16}$	62	$56\frac{1}{2}$	56	$31\frac{1}{8}$	$23\frac{3}{4}$	$28\frac{1}{2}$
34 -100	75	68	$62\frac{1}{4}$	$61\frac{1}{2}$	$35\frac{1}{2}$	$27\frac{1}{4}$	$31\frac{1}{2}$
50 -100	82	$76\frac{1}{4}$	70	68	$40\frac{1}{4}$	$27\frac{3}{4}$	36

Constant-current motors, being connected in series, must first be short-circuited by closing the main circuit around them, after which they may be disconnected.

Special forms of arc-circuit switches accomplish this by a single throw of the handle. The design of motor illustrated in the line drawings, Fig. 84, is well suited to driving fans. The dimensions of these motors for different voltages and power are given in Table XXVI.

Fan Motors.—The motors shown in Figs. 85 and 86 are especially adapted to the driving of large fans at low speeds, and are designed for direct connection with the fan shaft. The dimensions of different sizes of the motor, Fig. 85, are given in Table XXVII. The dimensions of the motor, Fig. 86, are given in Table XXVIII.

Table XXIX. gives the horse power per 100 revolutions for these motors, and the maximum speed at which they should be allowed to run.

Table XXIX.

Horse Power per 100 Revolutions and Maximum Speed for Fan Motor.

Size number	Type of machine	Horse power per 100 revolutions	Maximum permissible revolutions per minute	Weight, pounds
1 -100	Tripod Type	1	900	425
1½-100		1½	900	550
2 -100		2	750	800
3 -100		3	750	950
4 -100		4	650	1,200
5 -100		5	650	1,300
6 -100		6	575	1,550
8 -100	Pedestal Type	8	575	1,800
10 -100		10	475	2,200
12½-100		12½	475	3,000
15 -100		15	450	4,000
24 -100		24	400	6,000
34 -100		34	350	9,000
50 -100		50	325	13,000

CHAPTER VIII.

ELECTRIC LIGHTING.

Electric lighting may be divided into two general classes, according to the kind of lamp used, and known as *incandescent* and *arc* lighting.

Incandescent Lighting.

We know that one of the results of passing a current of electricity through a conductor is to heat it, and the greater the resistance, the higher the temperature to which it is raised. Then by passing a current through a conductor of sufficiently high resistance it may be heated to incandescence, and thus be made to give off light. The ordinary incandescent lamp consists of a glass bulb from which the air has been exhausted; inside of this is a thread or filament of carbon through which the current is passed (see Fig. 87). The resistance of this filament is so great compared with the current which flows through it that it becomes heated to incandescence.

Candle Power and Voltages Used.—Commercial incandescent lamps are made for various voltages, but for parallel distribution 110 or 220 volts are generally used. The higher voltage is very satisfactory for lamps of higher power, but should not be used for those of less than 16 candle power (c. p.). The majority of lamps for general illumination are operated at or near 110 volts.

Incandescent lamps are commonly made for 8, 16, 24, 32, and 50 c. p. each, although the 16 c. p. is the one most frequently used for the lighting of offices and dwelling houses.

Efficiency.—By the efficiency of an electric lamp is meant the power required at the lamp terminals per mean horizontal candle power, and is usually expressed in watts. The average 16 c. p. lamp when new, and on a 110-volt circuit, takes a current of about 0.5 of an ampere, and has an efficiency of about 3.5 watts per c. p. The illuminating power of a lamp decreases with use, and a reduction to 80 per cent of its original candle power is generally taken as the point at which it should be renewed. The normal life of a lamp under average conditions is not far from 800 hours.

Incandescent lamps can be run either on an alternating or direct-current circuit, and are especially adapted to the lighting of dwellings, offices, etc., as they produce a steady light, give off but little heat, and do not vitiate the atmosphere like gas or kerosene.

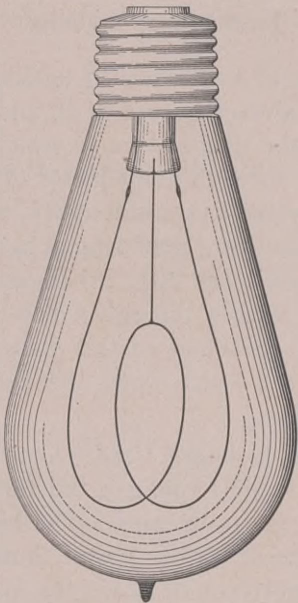


Fig. 87. Carbon Filament Incandescent Lamp.

Special Lamps.—There are a number of special incandescent lamps in use, among the more common being the Meridian lamp, the Tantalum lamp, the Nernst lamp and the Mercury Vapor lamp.

Meridian Lamp.—This lamp is intermediate in size between the arc and ordinary incandescent lamp. The filament is of special form and enclosed in a ground glass bulb, from 3 to 5 inches in diameter, according to the size of lamp. It is fitted with a reflector at the top conforming to the shape of the bulb as shown in Fig. 88, and gives a soft and uniformly distributed light. It is made in two sizes of 25 and 50 candle power each; the former requiring 60 watts and the latter 120 watts, making the efficiency about 2 watts per c. p.

These lamps may be used on either alternating or continuous-current circuits at standard voltages.

Tantalum Lamp.—This is an incandescent lamp with an extended filament as shown in Fig. 89. They are rated at 22 c. p and require 44 watts, thus having an efficiency of 2 watts per c. p.

Fig. 88. Meridian Lamp.

Nernst Lamp.—The light-giving element in this lamp is a small rod of porcelain called the *glower*. The current passing through this heats it to a very high temperature, thus producing a brilliant light of a white color. This type of lamp is used extensively only on alternating-current circuits at a frequency of about 60 cycles, and preferably at 220 volts. It has a better efficiency than the incandescent, but not so good as the arc lamp. From one to six glowers are commonly used, requiring about 88 watts each, or 0.4 ampere at 220 volts. These lamps operate without a vacuum, and can be renewed at will. One-glower lamps are rated at 50 c. p.; two glowers at 100 c. p.; three glowers at 170 c. p., and six glowers at 400 c. p. In appearance they are similar to the Meridian lamp shown in Fig. 88.

Mercury Vapor Lamp.—The Cooper-Hewitt or Mercury Vapor lamp is being used to a considerable extent where the quality of the light is not of great importance. In this lamp mercury vapor rendered incandescent by the passage of an electric current is the source of light.

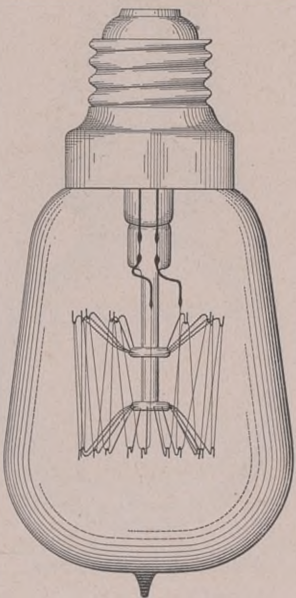


Fig. 89. Tantulum Lamp.

The electrodes are connected at the ends of a glass tube from which the air has been exhausted. The lamp as now constructed will operate only on a direct current, although an alternating lamp is being developed. It is not made in small sizes for ordinary voltages, and the light is very objectionable for the purpose of distinguishing color, owing to the entire absence of red rays. It is easy on the eyes, but its use is limited to the lighting of shops, offices and drafting rooms, or in display windows, where the goods shown are not changed in appearance by its color.

The type K lamp on a 110-volt circuit requires a current of 3.5 amperes, has an efficiency of about 0.55 watt per c. p. and is rated at 700 c. p. This lamp is shown in Fig. 90.

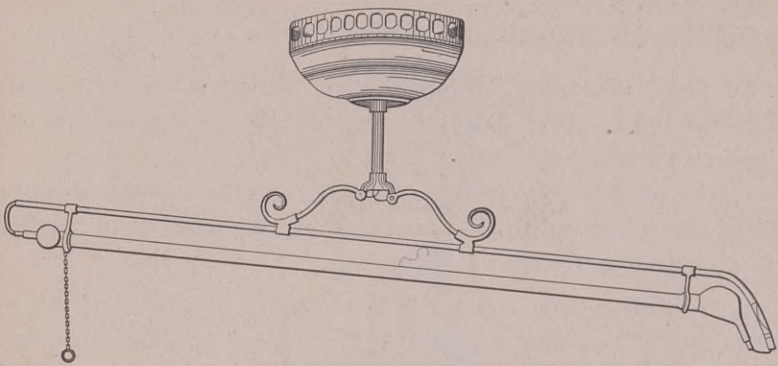


Fig. 90. Cooper-Hewitt Mercury Vapor Lamp.

Arc Lighting.

If a current of electricity of sufficient strength is passed through two pieces of carbon which are at first in contact and then separated there will be produced at this interruption in the circuit a voltaic arc, which gives out a brilliant white light and has an intense heat. The carbon tips or electrodes of the electric light operate in this manner. As they become highly heated, a portion of the carbon is vaporized, and this vapor heated to incandescence forms the arc. Although a certain amount of light is emitted by the arc, the greater portion is given off by the carbon tips themselves.

Arc lights are mostly used for lighting streets, halls, stores, or in general where large areas are to be illuminated. The color of the light is almost pure white, closely resembling sunlight, and is therefore desirable in shops and factories where colors are to be brought out in their true relation.

Types of Arc Lamps.—There are in use at the present time five distinct types of arc lamps, as follows:—

1. Series direct current.
2. Series alternating current.
3. Multiple direct current, 110 volts.
4. Multiple direct current, 220 volts.
5. Multiple alternating current, 110 volts.

Of these, the series direct current is the oldest and at present the least used, being gradually replaced for street lighting by the series alternating-current lamp.

In the older forms, known as *open arcs,* the carbons are exposed to the atmosphere and are therefore consumed quite rapidly, it being necessary to renew them daily.

Current Required.—Each *full arc* requires a current of 9.5 to 10 amperes, and *half arcs* 6.5 to 7 amperes at about 50 volts. They are run on a constant-current circuit, and being connected in series a high voltage is required. For example, if 50 lamps are connected in series, and each requires 50 volts, an electromotive force of $50 \times 50 = 2{,}500$ volts must be supplied by the generator.

Closed Lamps.—The open arc is now being rapidly displaced by the *closed* lamp, typical forms of which are shown in Figs. 91 and 92. These are much the same in principle as the open lamps, except they are provided with a nearly airtight globe or bulb which greatly reduces the combustion of the carbons. Lamps of this type will burn from 100 to 160 hours without re-trimming.

The standard enclosed direct-current series lamp of the General Electric Company takes a current of 6.6 amperes with a voltage of 77 at the terminals.

Series alternating-current enclosed lamps are commonly made in sizes taking 6.6 and 7.5 amperes, and require about 77 volts at the terminals.

Multiple Arc Lamps, so called, are made to run on constant potential circuits in the same manner as incandescent lamps. These are made in various sizes both for direct and alternating currents.

Multiple alternating-current lamps are more commonly used on 110-volt circuits, although made for 220 volts when desired.

The standard 110-volt lamps of the General Electric Company take 4, 6 and 7.5 amperes each.

Fig. 91. General Electric Enclosed Arc Lamp.

Efficiency.—The direct-current open lamp has an efficiency varying from 0.6 to 1.25 watts per c. p., while that of the enclosed lamp is somewhat greater, depending upon the type of globe used.

Rating of Arc Lamps.—As it is very difficult to measure with accuracy the illuminating power of an arc lamp, it is customary to use the ampere or watt rating instead of expressing it in candle power as may be done in the case of incandescent lamps. Ratings for different types of arc lamps have already been given.

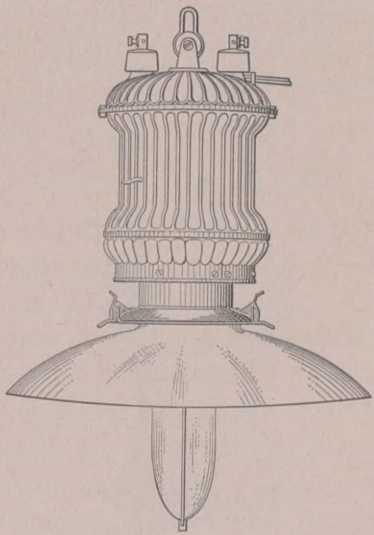


Fig. 92. Westinghouse Arc Lamp.

Number of Lamps Required.

The unit of illumination is the *candle foot,* and its value is the amount of light falling on a surface at a distance of 1 foot from a source of light 1 candle power in value.

The amount of illumination required in any particular case will depend upon the use to be made of the room. One candle foot gives sufficient light for easy reading when measured normal to the page, and 0.5 candle foot on a plane 3 feet from the floor is usually ample for ground illumination.

Accurate designs for the lighting of buildings are generally laid out along these lines, the effect of the reflecting power of walls and ceilings being taken into account.

For approximating the size of engine and generator in any particular case it is usually sufficient to simply consider the square feet of floor space to be lighted.

With incandescent lamps this may be based upon the candle power and with arc lamps upon the wattage.

Candle Power Required for Different Buildings.—For dwelling houses with brilliant illumination, 1 candle power may be allowed for each 2 to 3 square feet of floor space, and for general illumination 1 candle power for each 4 to 5 square feet of floor space, strengthened by special lamps where required.

In the case of offices, public halls, etc., 1 candle power is required for each 3 to 4 square feet of space for ordinary conditions, while for brilliant illumination, or where the ceilings are very high, this should be reduced slightly. Drafting rooms require 1 candle power for each 1.5 to 2 square feet of floor space to give the best results.

In the case of enclosed arc lamps with opal globes, we may assume the following requirements, expressed in watts at the lamp terminals:—

TABLE XXX.

WATTS PER SQUARE FOOT OF FLOOR SPACE REQUIRED FOR ARC LAMPS WITH OPAL GLOBES.

Location of lamp	Watts per square foot of floor space
Clothing stores	1.30
Halls	1.00
Drafting rooms	2.00
Machine shops	0.75
Weave rooms	1.20

Horse Power Required.

Having a system of lamps to be supplied with electric current, the required size of engine and dynamo may be obtained in different ways, depending upon the data at hand. If the efficiency and candle power of the lamps are known, the total number of watts may be computed, from which the capacity of dynamo and engine are easily determined.

Example.—A building is to have 700 incandescent lamps of 16 c. p. each; 200 Meridian lamps of 25 c. p. each; 20 multiple arc lamps requiring 4 amperes each, and 10 requiring 7.5 amperes each. The system is to be supplied with an alternating current at 110 volts. What will be the required capacity of dynamo and the indicated horse power of the engine, assuming efficiencies of 90 per cent and 88 per cent respectively and neglecting losses in the line?

From data previously given, we have:—

$700 \times 16 \times 3.5 = 39{,}200$ watts for incandescent lamps.
$200 \times 60 = 12{,}000$ watts for Meridian lamps.
$20 \times 4 \times 110 = 8{,}800$ watts for small arc lamps.
$10 \times 7.5 \times 110 = 8{,}250$ watts for large arc lamps.

Total, 68,250

$68{,}250 \div 1{,}000 = 68.2$, or in round numbers, 70 Kw., the required capacity of dynamo.

$68{,}250 \div 746 = 92$ H. P. required in the form of electrical energy to be supplied at the lamp terminals.

H. P. delivered to dynamos $= 92 \div 0.90 = 102$.

I. H. P. of engine $= 102 \div 0.88 = 116$.

Another method is to find the total current in amperes required by all of the lamps, then, knowing the voltage at which they are to operate, the number of watts can be determined at once.

Example.—What will be the required capacity of dynamo and engine to supply the current for a 110-volt parallel system, carrying 500 incandescent lamps of 16 c. p. each; 100 of 32 c. p.; 20 Cooper-Hewitt lamps; and 50 arc lamps?

Assuming average values for currents required for each type of lamp, we have

$500 \times 0.6 = 300$
$100 \times 1.2 = 120$
$20 \times 3.0 = 60$
$50 \times 5.0 = 250$

Total, 730 amperes

$730 \times 110 = 80{,}300$ watts, or 80.3 Kw.

$80{,}300 \div 746 = 108$ H. P. to be delivered by the dynamo in the form of electrical energy.

From this, the I. H. P. of engine can be computed as before.

Systems of Wiring.

The systems of wiring most commonly used for lighting are the *series, multiple-series,* and *parallel.*

The series system is the simplest of the three and is used principally for arc and incandescent lamps when applied to street lighting. Although used primarily for arc lights, it may be adapted to incandescent systems on lower voltages.

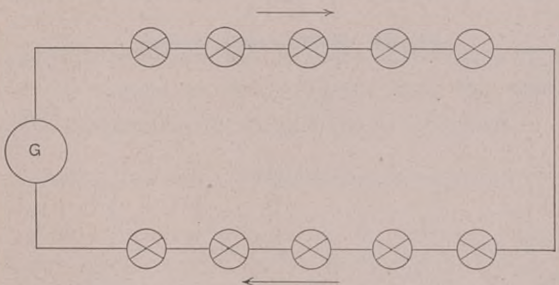


Fig. 93. Arc Light Circuit, Lamps Connected in Series.

Its advantages are simplicity and saving in wire; its disadvantages are the high voltages, which are fixed by the number of lamps in series. Fig. 93 shows the method of connecting lamps in series. The voltage necessary in any series system is equal to the sum of the voltage required by all the lamps on the circuit, plus that required to overcome the resistance of the wire. For example, if the lamps shown in Fig. 92 are arcs, and the circuit is short, a voltage of $10 \times 50 = 500$ will be required.

Multiple-series systems combine several lamps in series, and these in multiple or parallel as shown in Fig. 94.

The most common method of distribution is the multiple or parallel system. In this arrangement the lamps are connected across the lines as shown in Fig. 95. Systems of this kind are run on a constant-potential circuit, and the current delivered by the generator depends entirely upon the number of lamps in service.

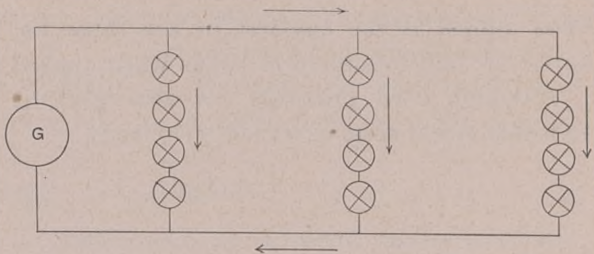


Fig. 94. Multiple Series System.

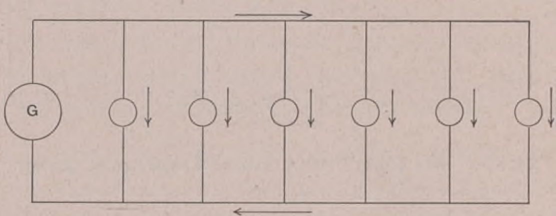


Fig. 95. Two-wire Parallel System.

The principal obstacle to the use of a system of this kind is that the voltage drops as the distance from the generator increases, so that the lamps at, or near the end of the line are not as bright as those near the generator. This may be overcome in different ways, one of which is to vary the size of the distributing wires along the line.

Multiple-wire systems are used to a large extent for both incandescent and arc lighting. The three-wire system shown in Fig. 96 is the most common of these. In this arrangement the difference in voltage between A and C and C and B is the same as for a simple parallel system.

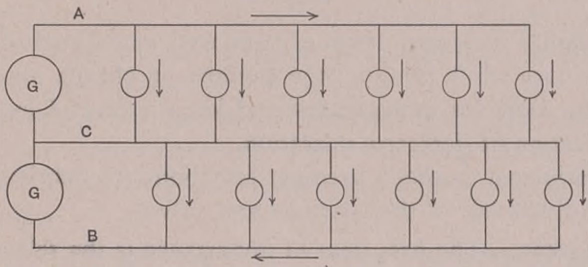


Fig. 96. Edison Three-wire Parallel System.

Two generators connected in series are required for this arrangement, as shown in the diagram, and the neutral wire is joined to the connection between them as indicated.

CHAPTER IX.

CARE AND MANAGEMENT OF STEAM ENGINES AND GENERATORS.

Engines.

Although a properly designed and well made engine requires but little care while running, the engineer in charge must always be on the alert for emergencies and keep a careful lookout for any indication of defective operation.

The principal matters needing attention are lubrication and proper adjustment of the bearings and valves.

Lubrication.—The first item of importance is the selection of a suitable oil. For cylinder lubrication a heavy mineral oil should be used, as animal oils are decomposed by heat and form a hard coating upon the internal surfaces of the cylinder and steam chest. For journals and other bearing surfaces this should be thinned somewhat with a lighter organic oil. Cylinder lubrication is usually effected by means of an automatic sight-feed lubricator, in which the oil is made to pass drop by drop through a glass tube filled with water, as it is fed into the steam pipe above the throttle valve. The method of supplying oil to the different bearings varies with the make and type of engine. For slow-speed engines, oil cups are commonly used, but with high-speed engines it is customary to use some form of forced lubrication, either by means of a small pump or by feeding from an elevated reservoir.

The main bearings are often provided with a tallow cup in the cap of the bearing, in addition to the regular oil cup or automatic feed. This is for use in case the oil supply fails for any reason and the bearing becomes heated, as under these conditions the tallow will melt and flow into the bearing as needed. Should it ever become necessary to cool a bearing with water, it must be done very slowly in order to prevent cracking or warping the metal by too sudden contraction.

Adjustment of Bearings, Stuffing Boxes, etc.—This is an important matter which requires constant attention. Horizontal engines should be watched for signs of wear upon the lower part of the cylinder, due to the weight of the piston. The piston rings require careful adjustment in order to avoid cutting the cylinder walls, and the piston rod must be kept exactly central to prevent excessive wear in the stuffing box and also to prevent springing the rod itself.

Stuffing boxes must be kept well packed and adjusted, and the packing should be renewed as often as necessary to keep a tight and smoothly working joint.

The connecting-rod bearings at both the crank and wrist pins should receive careful attention, as the "knocking" so often heard in engines is generally caused by a slight wearing of the brasses at these points.

The main bearings should be examined frequently, and any lateral movement taken up by proper adjustment of the side boxes, and in the case of high-speed engines the caps should be tightened occasionally to prevent any upward movement of the shaft.

Starting an Engine.—Before starting an engine the condition of the boilers should be noted to see that steam is up and the water-line at its normal position. All tools and loose parts must be removed from the engine, oil cups and cylinder lubricator filled and adjusted, and the drain cocks opened. The throttle valve may now be opened sufficiently to allow a small quantity of steam to blow through to warm up the cylinder and adjacent parts and to clear them of condensation. In engines of large size it is customary to work the valve gear by hand for a few revolutions until it is seen that everything is in running order. Those of smaller size may be slowly brought up to speed by means of the throttle valve alone. The drip cocks should remain open until all water is expelled from the cylinder.

An engine should be started slowly, not only as a precaution against accidents to itself, but also to avoid priming at the boilers, which is liable to occur if a sudden rush of steam is produced through the nozzles. When a condenser is used it should be started first, and stopped only after the engine has been shut down. In the case of a surface condenser, first start the air pump and when a sufficient vacuum has been formed start the circulating pump and then the engine as already described. If the condenser has a combination air and circulating pump, they must of course start at the same time.

The grease which accumulates on the tubes of a surface condenser should be removed occasionally by the use of a strong solution of soda. If a jet condenser is used, first start the pump, then partially open the injection valve and run the pump rapidly until the condensing water comes. Then speed the pump so that it will be just ahead of the water and the water valves can be heard to close with force. This will insure a proper emptying of the condenser and cause the highest vacuum to be formed. The engine may now be started as already described.

Priming.—This usually makes its presence known by a "slapping" sound in the cylinder, which is produced by the piston striking the water and throwing it against the cylinder heads. As soon as this sound is heard, the cylinder drains should be opened and a hurried inspection made of the separator to see if it is working properly. If there is considerable water in the glass on the separator, the by-pass around the trap which drains it should be opened wide.

When these precautions have been taken in the engine room, the engineer should visit the boilers and order the firemen to cover the fires of the priming boiler with fresh fuel. Meanwhile the water-level in the gauge glasses should be noted, and if any of them show high water the blow-off should be opened and the water brought down to its proper level. These precautions will, in nearly every case, stop the priming; but if they do not, the stop valve on the offending boiler should be partially closed so as to wire draw the steam and thus dry it. The engineer should always have a general oversight of the boilers, and before shutting down the engine he should notify the firemen so that the fires may be allowed to burn down somewhat before this is done.

Generators.

The following brief directions taken in connection with those already given for motors cover some of the more important features to be observed in the care of generators.

Cleaning.—Here, as in the case of motors, cleanliness should be given a prominent place, and better results can be obtained by cleaning the machine immediately after shutting down than by allowing it to cool. An air blast will be found useful for reaching the inaccessible parts and should form part of the equipment of a dynamo room where there are several machines to be kept in order. It is also well to provide each with a canvas cover for protection from dust after cleaning.

Direct-Current Generators (Shunt and Compound).

As direct and alternating-current generators differ in construction they will be taken up separately.

Starting.—Before starting, make sure that all tools and loose pieces of iron and steel have been removed from the machine. Note if the brushes are set and have the proper tension. Some engineers make a practice of bringing the generator up to speed before lowering the brushes. There is nothing gained by doing this and it is considered better to set them before starting unless the brushes are of such form that they would be injured should the machine for any reason be turned backwards.

Bring the generator to normal speed, and then gradually cut out the resistance of the rheostat, until normal voltage is obtained. Now note the operation of the machine, and see if the armature still oscillates freely in its bearings; if so, the generator is ready for its load. In case the generator does not "build up" to voltage when the field resistance is cut out of the circuit (with the generator running at proper speed) it will be found that either the residual magnetism has been lost, or that the shunt fields are not properly connected. In the former case, separately excite the fields from some other source of power for a short time. If, on reconnecting the fields, the generator does not build up, it is probable that the fields are wrongly connected; in this case reverse the leads as indicated on the connection diagrams. Also examine the brushes carefully to see that they make good contact with the commutator. If the machine does not then build up to voltage, an electrician should be called in to locate the trouble.

When the generator is excited to normal voltage, close the main switch. In the case of a shunt wound generator, to maintain the normal voltage as the load increases, it will be necessary to cut some of the resistance out of the rheostat.

In the case of a compound wound generator, if, as the load is increased with the speed remaining constant, the voltage drops to any great extent, it is probable that the series coils are opposing the shunt, and it will be necessary to reverse the series leads.

If the generator is operating on an independent circuit there is no harm in closing the main switch and allowing the voltage of the circuit to build up with the machine. With a large number of lamps, however, connected to the circuit, the field magnetism and voltage might not be able to build up until the line was disconnected. When running in parallel with other machines a generator should never be thrown in until its voltage is equal to or slightly greater than that of the circuit.

Test for Equal Voltages.—This may be made by first measuring the E. M. F. of the circuit and then of the machine, either by separate voltmeters or by a single one so connected that it may be thrown into either circuit as desired. Sometimes a differential voltmeter or a galvanometer is used.

A simpler way, although less accurate, is to raise the voltage of the generator until its "pilot lamp" is fully as bright as those on the line, and then connect the machine to the line. The lamps compared in this way must of course be for the same voltage and in normal condition in every way.

When the generator is first connected it should supply only a small amount of current to the line, and then gradually raise its voltage until it generates its proper share of the total current.

Operating.—The operator should be particularly careful that the oscillation of the armature is kept up, as it will greatly lengthen the life of both the bearings and the commutator.

Examine the oil occasionally, and if it shows any signs of grit or dirt draw it off and replace with fresh oil. When the machine is first started it is advisable to renew the oil at the end of each day's run until it is certain that there is no grit present. The oil rings should be examined occasionally to make sure that they revolve and carry up oil.

A heavy load should never be thrown on a generator suddenly if it can be avoided, but should be built up slowly by means of the different circuit switches. If the machine is operating in parallel with others, the shifting of the load should be done gradually. In the case of a new machine being run for the first time, it is best to operate it for a short period under a light load, giving special attention to any signs of excessive heating, either in the bearings, armature or field coils. Probably more trouble is caused from overloading than any one thing and special care should be taken to avoid this.

Stopping.—When stopping a machine which is running in parallel with others, gradually remove the load until its ammeter indicates little or no load and then open the switch. The speed should not be reduced or the magnetism weakened, else the dynamo will take current from the main circuit and run as a motor.

When a machine is operating on an independent circuit the speed may be gradually reduced until it comes to a stop, without touching either the brushes or switches. A generator should never be cut out at full or partial load except in case of an emergency. The brushes should never be lifted when a machine is in operation except when there are others on the same side to remain in contact.

Sparking.—There are various reasons for sparking, which vary with different types of generators. Some of the more usual causes of this trouble in direct-current machines are: brushes not set at the neutral point; current overload; rough commutator; open coil in armature; short-circuited coil; leak from coil to frame; weak or uneven magnetism; bad brushes; and excessive vibration of the frame.

If the brushes are not set at the neutral point they should be shifted by means of the rocker arm until this point is found.

In the case of sparking from overloading, the only remedy is to reduce the load until it ceases.

Care must always be taken at the start to keep the commutator in good condition. If for any reason it becomes rough or grooved it should be turned down or polished in a lathe.

An open coil can be detected by a spark which appears to travel nearly around the commutator.

This can sometimes be located by noticing which bar of the commutator is most damaged by the spark. A break of this kind seldom occurs in the coil itself, but where the wire is connected to the commutator bar, which makes it easily found and repaired.

A short-circuited coil will heat rapidly and is liable to burn out. It may be detected by holding a piece of iron between the pole pieces and noting if the strength of the magnetic attraction varies suddenly at a given point in each revolution. If this is found to be so, it shows that a defective coil exists.

A leak from the windings to the frame is commonly detected by means of a magneto bell.

Sparking will be caused by weak and uneven magnetism, generally due either to a break or short circuit in the field.

The brushes should be carefully fitted to the commutator in such a way as to insure the full area of contact intended, and the edges should be kept properly trimmed.

Vibration is usually caused either by an unbalanced armature or pulley, and in some cases by unsteady foundations. Vibration can sometimes be reduced by increasing the pressure of the brushes upon the commutator, but satisfactory running will not be obtained until the cause of the vibration has been removed.

Heating.—The degree of heat that is injurious may easily be determined by touching the various parts with the hand. If the heat is bearable to the hand it is harmless; but if not the trouble should at once be located and a remedy applied. As heat is easily transmitted from one part of a machine to another it is often difficult to determine its source. In cases of this kind it is best to stop the machine and allow it to cool, and then note which part first shows signs of heating after starting again.

Alternating-Current Generators.

The following relating to the operation of alternating-current generators is given by permission of the Allis-Chalmers Company:

Starting Up.—In case the alternator does not operate in parallel with other machines the following instructions should be observed:

Bring the alternator and exciter up to speed and make sure that the oil rings are revolving freely. See that all resistance in both exciter and alternator field rheostats is cut in and that both field and main switches are open. Cut out resistance in exciter field and bring the exciter pressure up to normal.

Close the field switch of the alternator and have all resistance in so that full voltage will not be generated in the windings. In case the machine is being started for the first time, allow it to run for an hour or two at low voltage and then gradually increase the voltage until it reaches normal; the load can then be thrown on. As the load increases it will be necessary to cut out some resistance in the field circuit in order to maintain full voltage, and if the load on the alternator is inductive a larger amount of resistance must be cut out than with non-inductive load.

On light loads comparatively small field excitation is required and it is advisable to run the exciter at rather low voltage and avoid wasting so much power in the field rheostat, provided the exciter voltage is not made low enough to render the operation unstable or cause sparking at the brushes, and that the exciter is not used for exciting other alternators.

Shutting Down.—Where a machine is run by itself and is to be shut down, first cut in resistance in the field of alternator, thus lowering the voltage. Then open the main switch and finally the field switch of the alternator. The alternator field circuit should not be opened when full current is flowing because the high induced E. M. F. caused thereby may be sufficient to break down the field insulation.

Parallel Operation.—When two or more alternators are run in parallel there are certain conditions that must be met in order to secure satisfactory operation. These are:

1. The machines must be in synchronism. That is, the frequency must be the same for each, and the E. M. F.'s of the different machines must be in phase.

2. The E. M. F.'s must be approximately equal.

3. In order to secure proper division of the load under changes in load conditions, the speed regulation of the prime movers must be alike.

4. To prevent periodic cross currents between machines, the variations in angular velocity of the prime movers must be kept

within certain limits. In waterwheel or steam-turbine driven units the angular velocity is uniform, but with reciprocating engine units there may be trouble due to periodic variation, if the engine flywheels are not heavy enough.

Belted Alternators.—With belted alternators it is very important that the pulleys be proportioned so as to make the speeds of the alternators such that they will give exactly the same frequency; if all the machines have the same number of poles their speeds must be exactly alike. If the pulleys are not of the proper size there will be excessive belt slippage or exchange of cross currents between the machines, thus causing fluctuations in voltage.

Engine-Driven Alternators.—With engine-driven alternators the speed can be varied by adjusting the governor, and there will be no trouble from cross currents provided the angular velocity of the engines does not vary too much, and the engine governors act properly.

Division of Load.—When two alternators are running in parallel their output (actual power) depends on the amount of power supplied by their prime movers. For example, suppose two engine-driven machines are running in parallel on a certain load and that each is taking half of the load. When the load increases there is a tendency for the speed to drop slightly and in order for the engine governors to act and admit more steam there must be a slight drop in speed. Now the two alternators must always run in synchronism, or at the same speed, assuming the number of poles to be alike, and if the drop in speed does not result in an equal increase in the steam admission of each engine one alternator will be supplied with more power than the other and the load will become unequally divided.

Changing the field excitation of the lightly loaded machine will not remedy matters (as with direct-current generators where the generators do not have to run in synchronism and have independent speeds). The only effect of changing the field excitation is to make a wattless current circulate between the two alternators, the actual amount of power supplied by each remaining the same. The only way to increase the steam and admission is by adjusting the engine governor, and to secure equal division of load under all conditions the change in speed for a given change in load must be alike for each engine.

When two or more alternators are run in parallel it is advisable to have an indicating wattmeter on each machine, so that the actual load will be indicated. In case wattmeters are not provided the load on each should be adjusted so that the sum of the currents as indicated by the machine ammeters will be a minimum for a given total current supplied to the line. If the sum of the machine currents is much in excess of the line current, it shows that a wattless current is circulating between the machines.

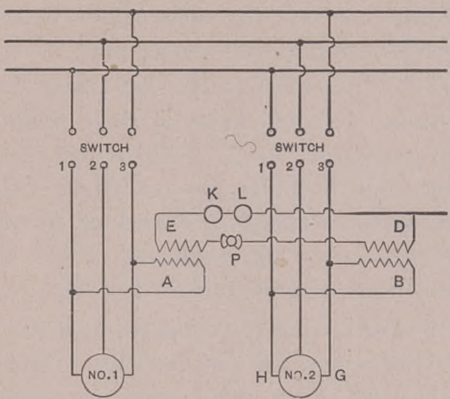


Fig. 97. Connections for Synchronizing Lamps; Lamps Bright at Synchronism.

Synchronizing.—The condition of synchronism is usually indicated either by incandescent lamps, or by a synchronism indicator or synchroscope, the latter now being used in most large installations. A synchroscope gives more accurate indications than lamps and has the additional advantage of showing whether the incoming machine is coming into or going out of phase and how much it is out of phase.

Figure 97 shows diagrammatically the connections for synchronizing lamps. Two small transformers *A* and *B* have their primaries connected to the same phase of each generator. The secondaries *E* and *D* are connected in series through a plug or switch *P*, and lamps *K L*. Assuming that corresponding terminals of the primaries are connected to corresponding lines on each machine and that the two transformers are alike in every particular, corresponding secondary terminals will, at any given instant, have the same polarity when the two machines are in phase.

When plug *P* is inserted, secondary terminals of opposite polarity are connected together; hence the two secondary E. M. F.'s are in series and aid each other in forcing current through the lamps *K L*, which are, therefore, bright at synchronism.

It may happen that the transformers are not wound exactly alike or that the connections have become confused; it is always advisable, therefore, to test the connections to make sure that the lamps are light or dark at synchronism. To test the connections in Fig. 97, disconnect *B* from generator No. 2 and transfer the connections, without changing their relative position, to lines *1* and *3* of generator No. 1; *A* and *B* will then be connected to the same lines and if the lamps are bright, they will also be bright at synchronism where *B* is connected to generator No. 2 as shown. If dark lamps are preferred, either the primary or secondary connections of one transformer may be reversed.

Another method of testing the connections is to leave the transformer connections as they are and disconnect the main leads *G H* on generator No. 2. Both main generator switches are then closed, thus connecting both transformers *A* and *B* to generator No. 1. In synchronizing, bright lamps are to be preferred to dark.

When a polyphase alternator is first connected up it is important to see that all of its phases correspond with those of the bus bars; if one phase only of a three-phase machine is correct, it does not follow that the other two are correct also. Two of the phases should be tested at the same time by using a pair of auxiliary transformers in addition to the regular synchronizing transformers *A B*, Fig. 98.

Transformer *A* is connected to the bus bars and *B* to the generator. A second pair of transformers *C D* is connected to one of the other phases, the connections in each case being such that the lamps are bright at synchronism. The connections should be tested as described above to make sure that the polarity of the transformers is correct.

With the main switch open and with the generator running at full voltage, both sets of synchronizing lamps should pulsate together. If they do not do so the leads from the generator are incorrectly connected to the generator terminals and should be interchanged so as to make the lamps pulsate together. After this test has been made, to insure that terminals *E, F, G* connected to the bus bars correspond to *E′, F′, G′* connected to the generator, the temporary transformers *C D* can be removed.

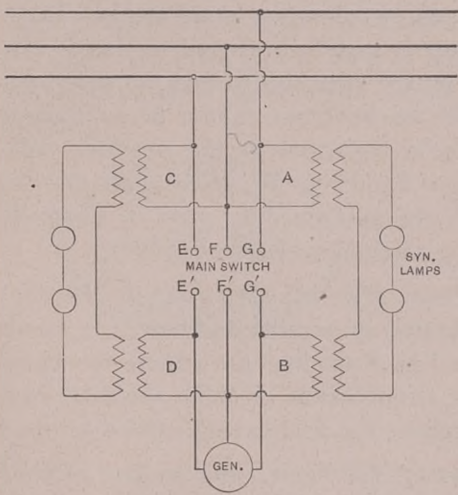


Fig. 98. Testing Two Phases at One Time.

Running Belted Machines in Parallel.—When a belted alternator is to be thrown in parallel with another machine, first bring the incoming generator up to speed and adjust the voltage until it is approximately the same as that of the bus bars. Adjust the speed until the beats of the synchronizing lamps become very slow, say one beat in 2 or 3 seconds, or until the pointer of the synchroscope is moving very slowly. Close the main switch when the lamps indicate synchronism (lights light or dark, depending on the connections), or when the pointer of the synchroscope is over the central point or slightly ahead of it. Adjust the field excitation and see that the alternator is supplied with enough power to make it carry its share of the load.

In case a number of belted alternators are driven from a common line shaft, the belt of the incoming machine should be slackened, thus introducing enough slip to allow the machine to be synchronized. After the alternator is in step the belt can be tightened and the load gradually applied.

Synchronizing Engine-Driven Machines.—With engine-driven alternators the incoming machine should be given only a small amount of steam until after it is synchronized. The load can then be taken up by admitting more steam. In large plants the engine governor is usually arranged so that it can be controlled electrically from the switchboard and the steam admission varied as desired. If the governor cannot be so controlled the steam admission can be regulated at the throttle. Waterwheel governors are also frequently provided with an electrical control device; if not, the gate opening must be controlled by hand to synchronize the machine and adjust the load.

Shutting Down Machine Operating in Parallel.—When machines are operated in parallel and one is to be shut down, first reduce the load by throttling the engine or slackening the belt. Then open the main switch. Cut in resistance in the field of the alternator to reduce the field current, and open the field switch.

General Care of Alternator.—On account of not having a commutator, alternators are on the whole much easier to keep in good running order than direct-current machines. At the same time they must be properly attended to. It must be remembered that they frequently generate much higher pressure than direct-current machines and there is all the more necessity for keeping them perfectly clean. No dirt, copper or carbon dust should be allowed to accumulate on or near the windings, and in plants sufficiently large to warrant the expense, it is advisable to install a compressed air system so that all dirt can be blown out of the corners not otherwise easily reached. It is also advisable to give the armature coils and connections a coat of insulating varnish occasionally.

Keep the collector rings lubricated with a small quanity of vaseline applied with a cloth and see that the brushes make good contact with the rings.

Never open the field current suddenly while current is flowing, and see that both main and field switches are open when the machine is not running.

Never throw machines in parallel when they are out of synchronism, the excessive rush of current throws heavy strains on the engines and generators and may cause considerable damage.

Remember that the alternators are designed for the voltage indicated on the name plate. They must not be expected to give voltages considerably above normal with satisfactory performance of either exciter or alternator. This point is here mentioned because frequent attempts to raise the voltage an excessive amount has resulted in poor operation through no fault of either exciter or alternator. Furthermore, the rated current output should not be continuously exceeded.