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No. 71

A Dollar's Worth of Condensed Information

Steam Turbines

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NUMBER 71

STEAM TURBINES

CONTENTS

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CHAPTER I

ACTION OF STEAM IN STEAM TURBINES

The extensive use of electricity in recent years, for power and lighting, has created new requirements in the design and construction of prime movers for the driving of electric generators. As a result, hydraulic machinery has been improved and adapted to this purpose, and the high-speed reciprocating engine, of the direct-connected type, has come into general use. The most important advance, however, along this line has probably been in the development of the steam turbine.

The steam turbine is especially adapted to central station work for the following reasons: It has a high speed, with close regulation; it gives high economy under variable loads; it works under conditions of practically adiabatic expansion of steam, the ideal condition sought for in the design of all steam engines; it eliminates cylinder condensation, because the passages through which the steam flows are always at practically the same temperature; it has no reciprocating parts, with rubbing surfaces to be lubricated; it produces no vibration which calls for expensive foundations; and finally, the floor space required is much less than for a reciprocating engine of the same power.

On the other hand, certain characteristics which adapt it especially to electric plant service make it unsuitable for general power work. These are as follows: It runs at a constant speed; it is not easily made reversible; and it operates at a normal speed so high that its power cannot be transmitted to other machines by ordinary methods.

Preliminary Theoretical Considerations

Before taking up the theory of the steam turbine, it may be well to give a few definitions, and explain briefly some of the more important principles in mechanics involved in its operation.

Work is commonly defined as the result of force acting through space. The rate at which work is done is called *power*.

Energy is the ability or power to do work under certain conditions. Energy manifests itself in various forms, the most common in mechanical operations being energy of motion, or *kinetic* energy; energy of position, or *potential* energy; heat energy; and electrical energy. Kinetic energy may be illustrated by a current of water flowing through an open trough or flume inclined sufficiently to give the water a considerable velocity. If the friction of the water against the walls of the flume is neglected, there is no resistance to its movement, and therefore no work is done. If now a paddle-wheel with shaft and bearings be supported above the flume in such a manner that the tips of the blades enter the water, they will be caught by the current, the wheel made to revolve, and work will be done.

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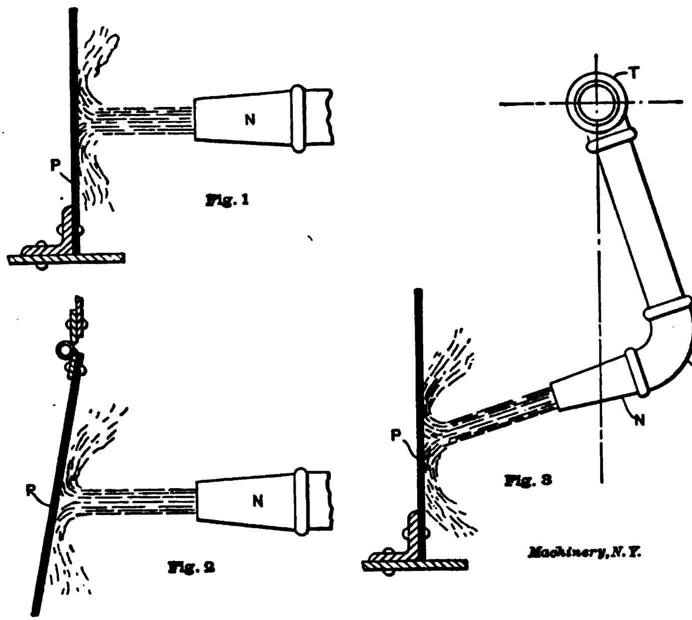
Thus it is evident that energy may be changed into work if the right conditions are present. The power or ability to do work was present in the running water, but no work was done until the water-wheel was placed in its path to effect the transformation. Air in motion possesses kinetic energy and may drive a windmill. Again, a clock-weight falling toward the earth, with an extremely slow movement, causes the various wheels of the clock mechanism to revolve, and so has its energy of motion changed into work.

Potential energy may be illustrated by the power producing possibilities of the water in the reservoir from which the supply was



Figs. 1 to 3. Illustrations of the Principles of Action and Reaction

drawn into the flume in the first illustration. While the gate was shut and no water passing through the flume, the contained energy was due to its elevation above the water-wheel. No work was being done, but the water had the power of doing work under the right conditions. When the gate was opened and the water began to flow down the flume, its potential energy was changed to kinetic energy; and again, when it reached the blades of the wheel and caused it to revolve, a part of the kinetic energy was transformed into work.

When a clock is wound up, but not put in motion, the weight has potential energy only, due to its height; but when the clock is started, and the weight begins its downward movement, it has both potential and kinetic energy, the former diminishing, however, as the weight descends towards the bottom of the clock.

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Heat energy is due to molecular vibration, and is therefore kinetic energy. Its transformation into work may take place in various ways, the action of the steam or gas engine being the most common example. Very little is known of the nature of electrical energy, but its change into work by means of the electric motor is familiar to all.

Action and Reaction

Action and reaction, more commonly called impulse and reaction, are best explained by means of a practical illustration. In Fig. 1 let *N* be a nozzle from which a jet of water is discharged at a high velocity against a flat plate *P*. If both are held stationary, it is evident that the effect is a *tendency* to force them apart, although no movement actually takes place. If now the plate be hinged at the top and is free to swing, it will be pushed away from the nozzle by the *impulse* of the jet of water impinging against it, as in Fig 2. On the

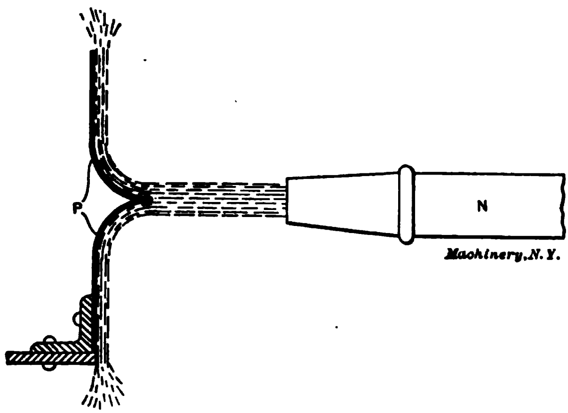

Fig. 4. Jet of Water Discharging against a Curved Plate

other hand, if the plate be kept stationary, and the nozzle made free to move by means of a trunnion *T*, as shown in Fig. 3, the nozzle will be forced back by the *reaction* of the jet, as shown.

It should be stated here, however, that the presence of the plate *P*, in Fig. 3, has no effect upon the position of the nozzle, as the latter is forced back solely by the reaction of the jet as it leaves the orifice, and not by any resistance caused by its striking against the plate. Reaction is due principally to an unbalanced pressure within the nozzle. It is evident that there is no internal pressure over the area occupied by the orifice through which the water is discharged, except that due to the resistance of the atmosphere. Hence the internal water pressure on an area equal to that of the orifice, and directly back of it (see *a*, Fig. 3), is unbalanced, and tends to force the nozzle backward in a direction opposite to that in which the jet is discharged.

As commonly defined, impulse is a force acting in a forward direction, and reaction an equal force acting in the opposite direction.

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Effect of Curved Plates

In Fig. 1 the jet strikes a flat plate, which breaks it up with a resulting loss of energy. In Fig. 4 a curved plate is substituted, of such form as to divide the jet and change the direction of flow, the two streams leaving the plate at right angles to the jet, as shown. The pressure against the plate is the same in this case as in Fig. 1, and is caused wholly by the impulse of the jet. The streams of water flowing from the plate in lines parallel to its face have no tendency to force it away from the nozzle.

In Fig. 5 the plate is so curved as to discharge the water directly backward toward the nozzle, the direction of flow having been changed through 180 degrees; in this case, the pressure tending to force the plate away from the nozzle is twice as great as in Fig. 4, because we have here not only the impulse of the jet, but also the reaction of the water as it leaves the plate.

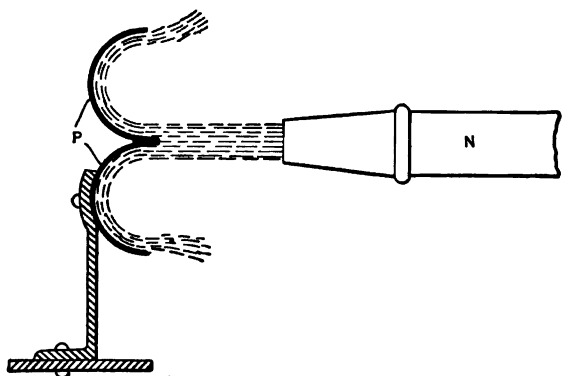

Fig. 5. Another Example of Jet Discharging against a Curved Plate

In the examples given for the purpose of illustrating the principles of impulse and reaction, a jet of water has been used instead of steam. This has been done for simplicity, and because water is, so to speak, a more tangible medium. The action of steam, so far as impulse and reaction are concerned, is practically the same, the only difference being in the greater velocity of a steam jet as compared with a water jet. One important characteristic of steam, not possessed by water, is the property of expansion. This is made use of in the steam turbine, but does not alter the principle of operation, which is practically the same as that of the hydraulic turbine.

Theory of the Turbine

It has been shown in Machinery's Reference Series No. 70, "Steam Engines," that a reciprocating engine is a machine for transforming the heat energy of steam into work. A steam turbine accomplishes the same result although in a somewhat different manner. In the former machine the heat energy is changed directly into work by exerting a static pressure upon the piston, causing it to move forward

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and backward, thus giving, by means of the crank, a rotary motion to the shaft. The amount of energy so obtained from the steam is increased by expanding the steam in the cylinder, thus lowering its pressure and causing it to give up heat which is transformed into work.

The turbine, unlike the reciprocating engine, makes use of the velocity of the steam instead of its static pressure. The heat energy of the steam is, through expansion, first changed into kinetic energy, and this in turn is transformed into work by the impulse and reaction effects produced by steam jets discharged through suitable nozzles against vanes upon the periphery of a revolving wheel. In both cases the work done is due to the heat energy contained in the steam. In the reciprocating engine the action is intermittent, while in the turbine it is continuous.

Turbines are divided into two general classes, known as the impulse and reaction types, according to the method in which the steam

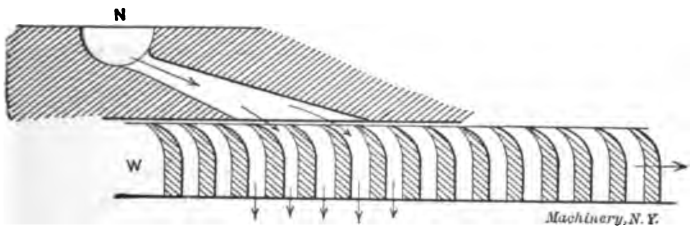

Fig. 6. Principle of Action of Impulse Turbine

imparts its energy to the revolving element of the machine. Strictly speaking, all practical turbines make use of both impulse and reaction. In some cases the impulse effect predominates, while in others reaction is depended upon for the greater part of the power developed. The real distinction between the two types is that in the impulse turbine the expansion of the steam is completed within the nozzle, but in the reaction type the steam continues to expand after it has entered the passages of the wheel.

Impulse Turbines

The impulse turbine, as its name implies, makes use of the impulse effect, so far as possible, for the development of power, the heat energy of the steam being first changed into kinetic energy by expansion in diverging nozzles. The rapidly moving particles of steam are then blown directly against the vanes of the turbine wheel, causing it to revolve as an effect of the pressure due to the impulse of the jets. As the expansion of the steam is completed within the nozzle before entering the passages of the wheel, it is evident that the pressure between the vanes is the same as that within the casing in which the wheel revolves, and that the motive force is due entirely to impulse and reaction and not to differences in pressure.

The action of an impulse turbine is shown in the diagrammatical view in Fig. 6, in which *W* represents a section of a turbine wheel,

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and N a nozzle supplying steam to the same. The direction of flow is indicated by the arrows, and the rotation is due entirely to impulse. The entering jet first strikes the vanes as shown, and forces them forward, after which the direction of the steam is changed by

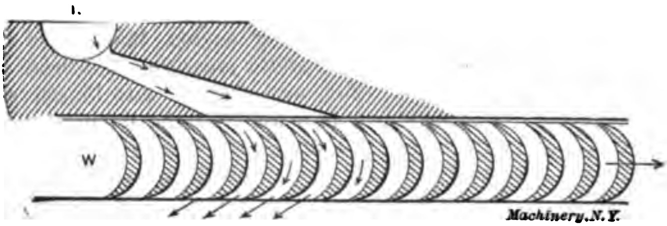

Fig. 7. Modified Form of Vane in Impulse Turbine

the curved form of the vanes, so that it passes out of the wheel in a direction parallel with the axis, and therefore without reaction.

The practical objection to a turbine of this design is its wastefulness in the use of steam, on account of the high velocity with which the steam leaves the wheel. The usual form of vane used in connection

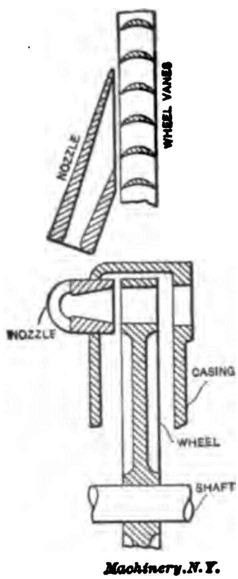

Fig. 8. Diagrammatical View of Construction of Impulse Turbine

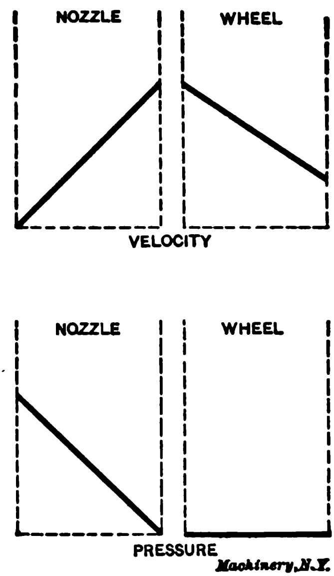

Fig. 9. Graphical Representation of Velocity and Pressure Changes of Steam in Impulse Turbines

with an impulse wheel is, therefore, modified to a form as shown in Fig. 7. In this case the steam leaves the wheel at an angle with the axis, thus producing a certain amount of reaction in addition to the impulse of the entering jet. Although in diagrammatical form, Fig. 8 shows the construction more in detail, and will lead to a clearer

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understanding of the design and operation of the actual machines to be described later. The upper illustration in Fig. 8 is essentially the same as that shown in Fig. 7, although placed in a vertical position. The lower part of the engraving represents a section through a part of the wheel, nozzle, and casing.

In studying the action of a turbine, a graphical representation of the velocity and pressure changes is often made use of, as shown in Fig. 9. In the upper diagram, the heavy lines represent the changes in velocity of the steam as it passes through the nozzle and wheel respectively. The lower diagram shows the corresponding changes in pressure. Referring to the upper part of the figure, it will be seen that the velocity of the steam increases at a constant rate during its passage through the nozzle, due to expansion. After entering the wheel, a certain amount of the kinetic energy is transformed into work, resulting in a corresponding drop in velocity, as shown by the downward slope of the heavy line through the wheel. The lower diagram of the figure shows that the pressure in the nozzle drops as expansion

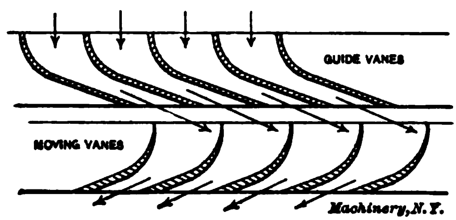

Fig. 10. Principle of Reaction Turbines

takes place, and that no further change occurs as the steam passes through the vanes of the wheel.

Reaction Turbines

In turbines of the reaction type, the steam is only partially expanded in the nozzle, the expansion being completed after its entering the wheel, the steam thus attaining a still higher velocity. In the impulse turbine the pressure is the same upon both sides of the wheel, as shown in Fig. 9, while with the reaction type, the steam leaves at a lower pressure than it enters, on account of the expansion which has taken place during its passage through the wheel. For this reason the buckets or vanes of the reaction turbine, as shown in Fig. 10, differ in form from those of the impulse type, and although commonly known as buckets, they really act as nozzles.

The path of the steam is indicated by the arrows. The steam first strikes the vanes in such a manner as to impart a certain pressure by impulse. Its direction is then changed, and it leaves the wheel at such an angle as to react strongly upon the vanes, thus producing the greater part of the power developed in this way. It will be noticed in Fig. 10 that the usual form of nozzle has been replaced by so-called guide vanes. This method of steam distribution is commonly used in reaction turbines, and also in some forms of the impulse turbine.

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Compound Turbines

The turbines thus far described, both impulse and reaction, are known as *simple* turbines; that is, the steam from the nozzles or guides has been directed against the vanes of a single wheel. The objection to this arrangement is the excessively high speed at which the wheel

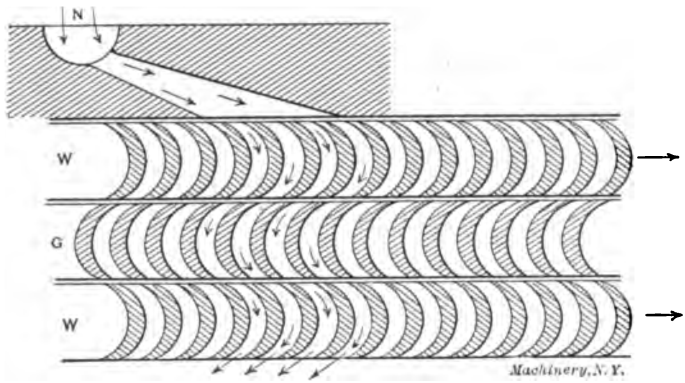

Fig. 11. Diagrammatical View of Compound Impulse Turbine

must run in order to utilize the energy of the steam. Certain turbines of comparatively small size are designed on this principle, and the power is transmitted by means of special gearing. The method more commonly employed, especially in the case of large machines, is to use several wheels attached to the same shaft, alternating with stationary guides. With this arrangement only part of the energy of the steam is imparted to each wheel, and a much lower speed is possible.

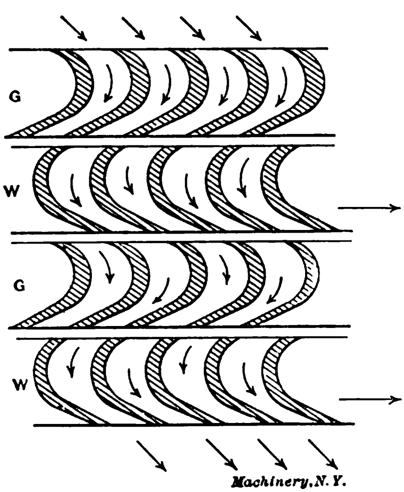

Fig. 12. Diagrammatical Section of Compound Reaction Turbine

A compound impulse turbine having two wheels is shown in the diagrammatical view in Fig. 11. The steam is first expanded in nozzle *N*, and then passes through the first wheel in the manner already shown in Fig. 7, except that in this case a smaller proportion of the kinetic energy has been changed into work, and the steam issues from the wheel at a much higher velocity. It now enters the stationary guide vanes *G*, which reverse its direction of flow, and then passes into the second wheel in precisely the same manner as it did the first, where still more energy is transformed into work.

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Theoretically, an arrangement of this kind will reduce the speed to one-half that of a simple turbine, with the steam entering and leaving the wheel at the same velocities. In like manner, three wheels would reduce it to one-third, and so on. Actually, this ratio is not carried out exactly, on account of other conditions which must be considered, but the above method is successfully employed in bringing the speed down to a point where it becomes practicable to transmit the power developed by the turbine to other machines. In the case of electrical work, the speed of the turbine and generator are so

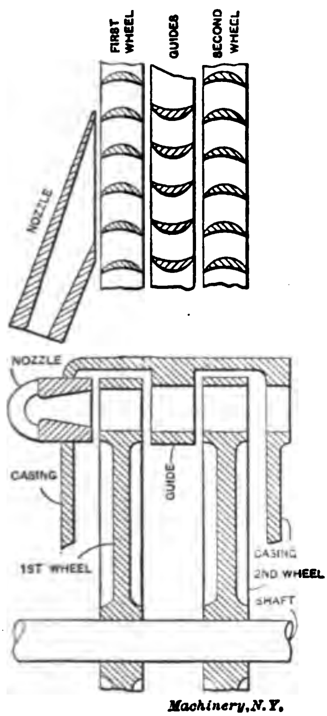

Fig. 13. Section through Wheels and Casing of a Compound Impulse Turbine

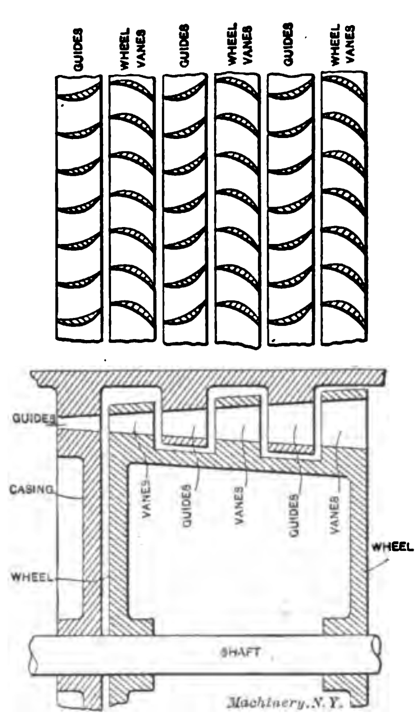

Fig. 14. Partial Section through Wheel and Casing of a Compound Turbine of the Reaction Type

adapted to each other that the turbine wheel and the armature are placed upon the same shaft.

Fig. 12 shows in diagram a section from a compound turbine of the reaction type. This is similar to Fig. 11, except in regard to the form of the buckets or wheel vanes. A partial section through the wheels and casing of a compound impulse turbine is shown in Fig. 13, and velocity and pressure diagrams for the same machine in Fig. 15. In this case the velocity rises to a maximum in the nozzle, then drops a certain amount in passing through the first wheel, flows through the guide vanes without change, and falls practically the same amount

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in the second wheel as in the first. The lower diagram shows, as already stated, that no change in pressure takes place after the steam leaves the nozzle.

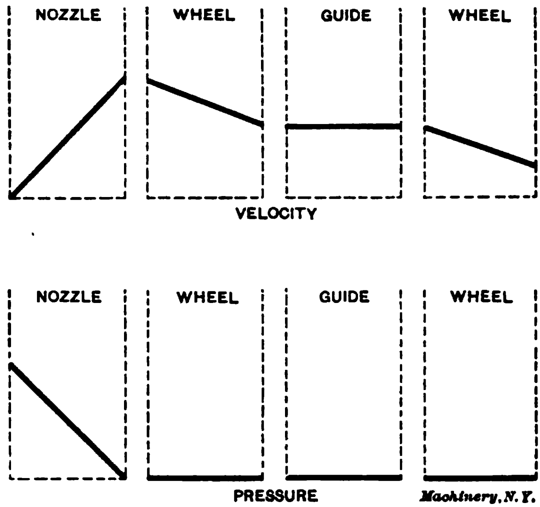

Fig. 15. Velocity and Pressure Diagrams for Compound Impulse Turbine

Fig. 14 shows a partial section through a compound reaction turbine having three wheels. This differs from the impulse turbine shown in Fig. 13 not only in the angle of the blades, shown in the upper section,

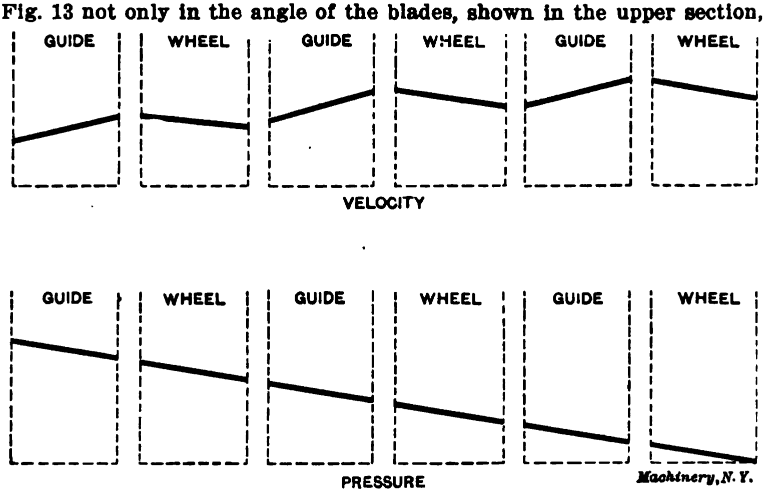

Fig. 16. Velocity and Pressure Diagrams for Compound Reaction Turbine

but also in the form of the passage through the guides and wheels in the lower section. In Fig. 13 this passage is of practically the same size or cross-section for its entire length, indicating that no expansion takes place after the steam leaves the nozzle. The passage in Fig. 14 in-

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creases in size regularly from inlet to outlet, which shows that expansion must take place within the turbine itself, which, as mentioned, is the chief characteristic of the reaction type.

Velocity and pressure diagrams for this turbine are shown in Fig. 16. Here the steam enters the first guide (at the left) at a certain initial velocity, which is increased by expansion as it passes through the guide ring. This velocity is partially absorbed in the first wheel, as shown by a downward slope of the line, but is again increased by further expansion in the second guide ring, and so on until the steam is discharged from the last wheel at the right. The pressure, in this case, instead of dropping to a minimum in the nozzle as in Figs. 9 and 15, falls gradually throughout the entire passage through the turbine, as shown in the diagram, and corresponds to the constant expansion in the guide rings shown above.

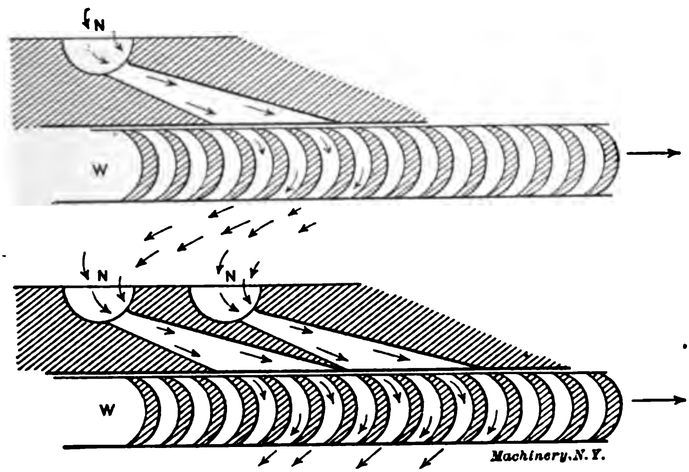

Fig. 17. Principle of Two-stage Impulse Turbine

Multiple Stage Turbines

Compound impulse turbines are sometimes divided into stages, that is, two or more groups of wheels and guides are arranged in separate compartments, each group being called a stage. This is illustrated in Fig. 17, which, in effect, is a series of simple turbines, the wheels of which are placed in separate compartments, and so arranged that the exhaust from the first wheel enters the casing of the second and passes through a second set of nozzles to the next wheel, and so on, according to the number of stages employed. It will be noticed in Fig. 17 that two nozzles are used to supply the second wheel. This is because the steam at this point has a greater volume than at first, due to its expansion in nozzle No. 1. The object of a stage turbine is to produce a gradual fall in pressure, by successive stages, rather than by a single drop as in simple forms, the action of which is shown in Figs. 9 and 15.

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CHAPTER II

TYPES OF STEAM TURBINES

Having taken up the general principles upon which steam turbines operate, some of the more common forms employed in American practice will now be described in detail. This will provide the best and easiest means of becoming familiar with the construction and operation of this type of machine.

The De Laval Turbine

The De Laval turbine is a simple impulse turbine, consisting of a single wheel in the periphery of which are inserted milled buckets or vanes of the form shown in Fig. 18. The steam is delivered against the buckets at a high velocity through nozzles ranging from one to

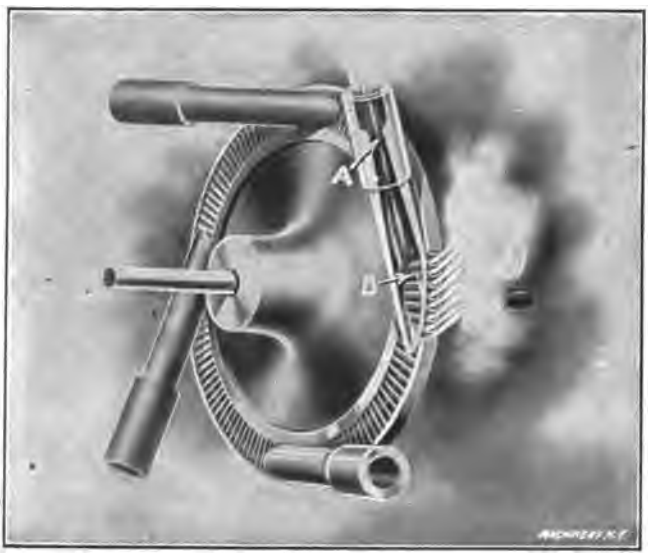

Fig. 18. Wheel and Nozzles of the De Laval Steam Turbine

eight in number. The expansion of the steam, which produces this high velocity, takes place in the diverging conical nozzle of each jet, the taper being so proportioned as to give the steam the proper expansion to cause it to attain its greatest velocity as it reaches the vanes of the wheel. At the same time, the initial pressure is gradually reduced at each increasing section of the nozzle to a final pressure equal to that of the atmosphere, or of the condenser, as the case may be. In this way all of the available heat energy of the steam is transformed into kinetic energy, and so utilized in driving the wheel.

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Referring again to Fig. 18, it is seen that the smallest sectional area of the nozzle at *A*, determines the quantity of steam which will pass through it, and the ratio of that area to the area at *B* determines the amount of expansion and thus the velocity of delivery. A section through one of the nozzles is shown in Fig. 19. The nozzles are equally spaced around the circumference of the steel casing which encloses the wheel. The steam chest, indicated in the illustration, is an annular space separated from the wheel chamber and connecting with the same through the nozzles. The inner ends of the nozzles project to within about ⅛ inch of the wheel blades.

A horizontal section through a complete turbine is shown in Fig. 20. Starting at the right, *W* is the turbine wheel attached to a flexible shaft which is supported at each side by specially constructed bearings. At the other end of the shaft are spiral pinions *K*, supported by the bearings *C* in the wheel casing, and meshing with the gears *H* as indicated. In order to obtain the highest efficiency in a turbine of this type, the wheel must run at a speed giving a peripheral velocity of

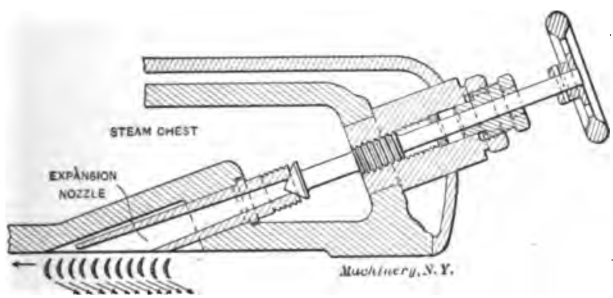

Fig. 19. Section through Nozzle of a De Laval Steam Turbine

about one-half that of the steam as it strikes the blades. In practice, the wheels of this turbine are made of such diameter that the speeds run from 10,600 revolutions per minute, for the largest size, up to 30,000 for the smallest. These speeds are reduced approximately 10 to 1 by the helical gearing already referred to in Fig. 20, giving the driving-shaft speeds of from 1000 to 3000 revolutions per minute. In case of the smaller types, a single gear is used, but in sizes from 75 to 500 horsepower, two sets of gears and two driving shafts are employed as indicated.

Power is transmitted to electric generators or other machinery by means of flexible couplings as shown at the left. These have a series of pins *F*, threaded into holes in the faces of the driving disks, and on their outer ends provided with rubber bushings *E*, which fit in corresponding holes in the coupling attached to the shaft of the generator.

Great care is taken in the design and construction of the wheel to guard against rupture due to the high velocity at which it runs. Speed regulation is secured by means of a centrifugal governor *M*, which in connection with a poppet valve in the supply pipe controls the flow of

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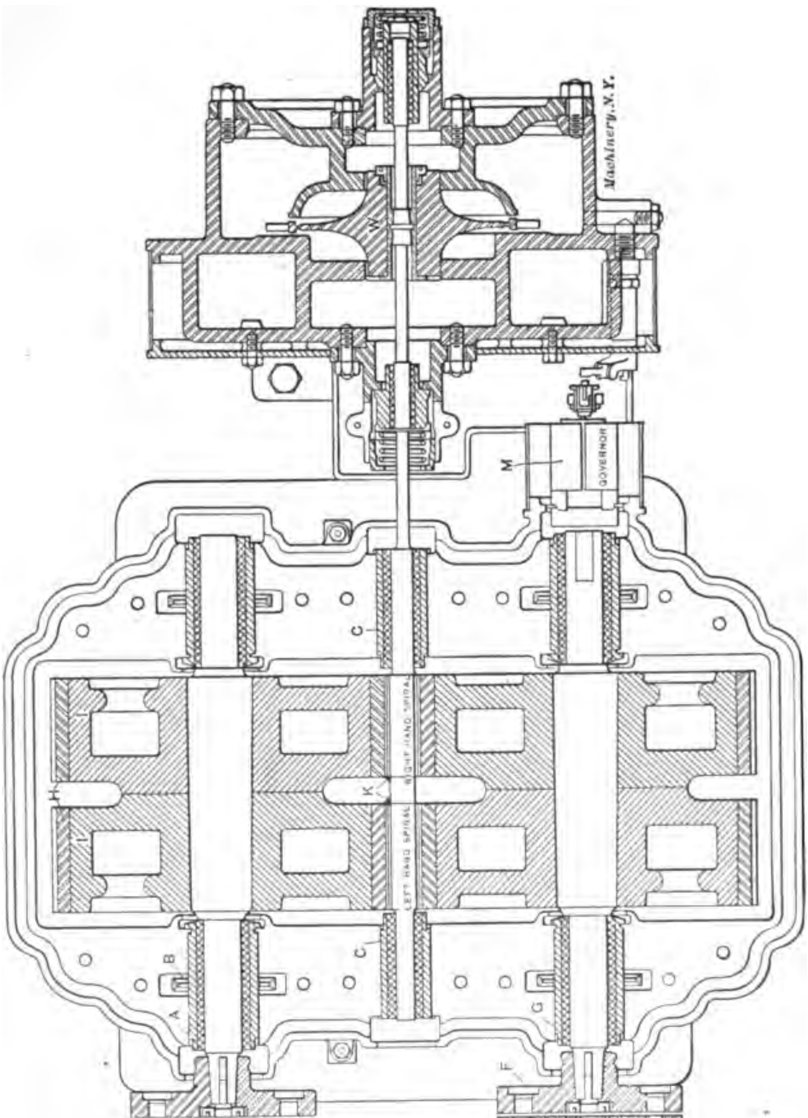

Fig. 20. Horizontal Section through Steam Turbine

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steam. Although this type of turbine is used to a considerable extent for the operation of centrifugal pumps and blowers, its widest application is in connection with electric generators, it being built for this

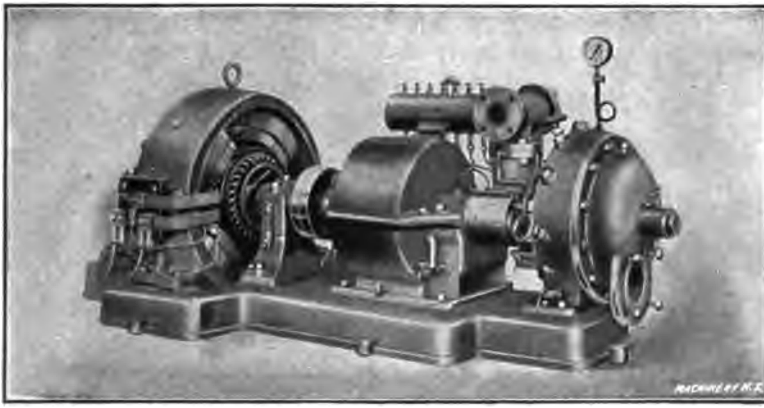

Fig. 21. De Laval Steam Turbine Direct-connected to an Electric Generator

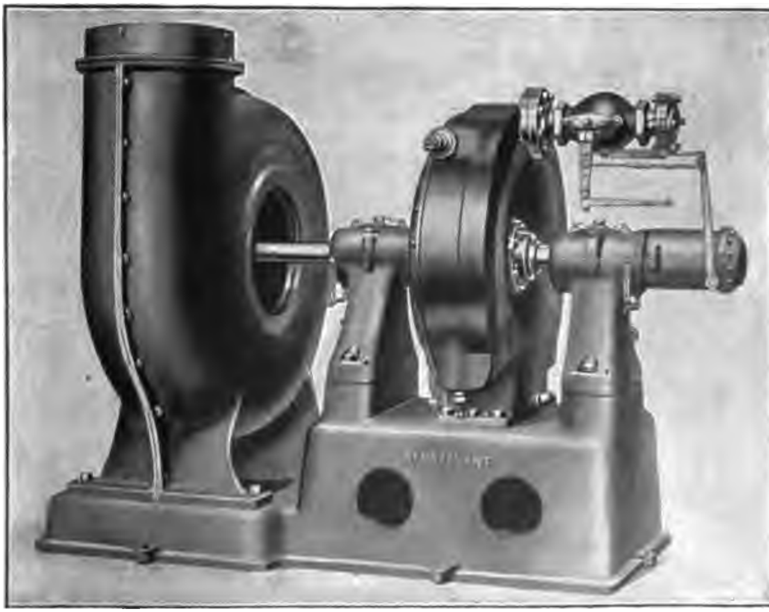

Fig. 22. Sturtevant Steam Turbine Driving a Gas Blower

purpose in sizes of from 7 to 500 horsepower. An exterior view of a direct-connected set of this kind is shown in Fig. 21, the turbine being at the right, the speed-reducing gearing at the center, and the generator at the left.

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The Sturtevant Turbine

The Sturtevant turbine is an impulse turbine of the so-called multiple-pass type. One of the single stage machines is shown in section in Fig. 23, and an elevation of the casing with the wheel partially removed in Fig. 24. Steam entering through the inlet *I* (Fig. 23), passes through and around an annular chamber *A* in the casing, from which

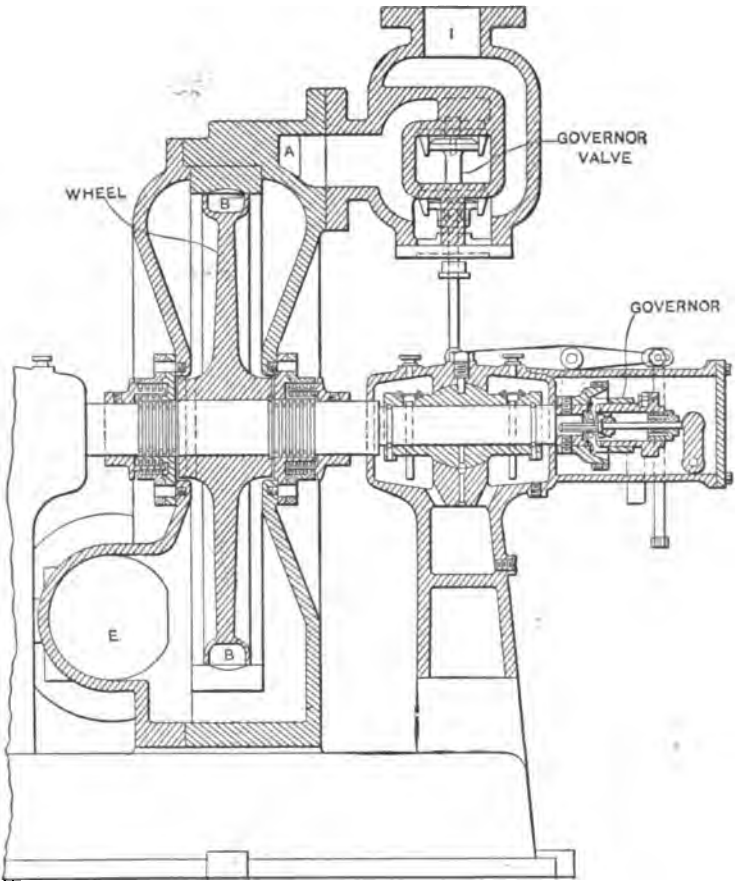

Fig. 23. Section of Single-stage Sturtevant Steam Turbine

it flows through nozzles designed to expand and deliver it at a high velocity at the point of impact on the bucket of the rotor or wheel. The openings from two of the nozzles are shown at *O* in Fig. 24. The bottoms of the buckets in the wheel are shaped to the form shown at *B*, Fig. 23, the buckets receiving the steam on one side and exhausting it from the other, having changed its direction of flow 180 degrees.

After leaving the wheel the steam passes into the stationary buckets

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in the reversing ring, shown near *O* in Fig. 24, and which are similar in form to the buckets on the wheel. From here the steam is again returned to the rotor buckets, and the process is repeated until the velocity of the steam drops nearly to that of the rotor, when it is allowed to pass into the exhaust chamber and out through the opening *E*, Fig. 23. The annular ring of high-pressure steam reduces radiation losses and makes the use of insulation unnecessary in the smaller sizes. The governor is of the centrifugal throttling type, the speed being changed either by altering the tension of the spring, or by adjusting the nuts on the rod leading to the throttle valve.

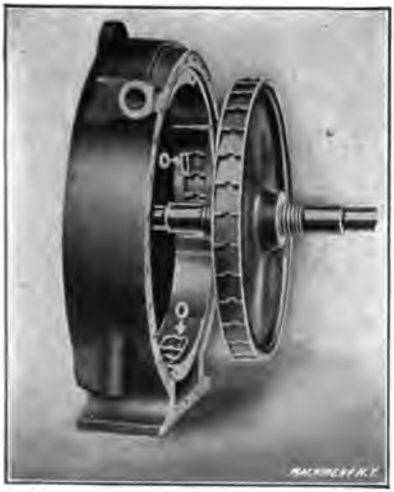

Fig. 24. Casing of Turbine with Wheel partially Removed

An external view of this type of machine attached to a gas-blower, is shown in Fig. 22. These turbines are also built in the multi-stage form, a three-stage rotor for a 250 horsepower machine being shown in Fig. 25. In another design of the single-stage type, the buckets are placed on the faces of the wheel, near the periphery, instead of around the edge as

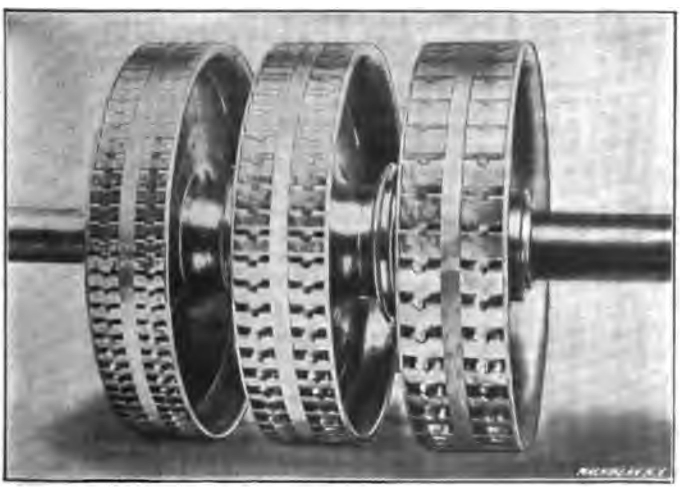

Fig. 25. Three-stage Rotor for Sturtevant Steam Turbine

in the type shown in Fig. 23. The nozzle openings are equally spaced around the circle, one-half on each side of the casing, and are provided with hand-valves for closing off if desired. They are operated in pairs

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and reduce the power without affecting the efficiency. The smaller sizes are of the single-stage type, while those above 200 horsepower are usually made with two to four rotors, depending upon the speed and amount of power to be obtained from the unit.

The Terry Turbine

The Terry turbine is similar in principle to the one just described, the wheel being fitted with semi-circular buckets as shown at *A* in

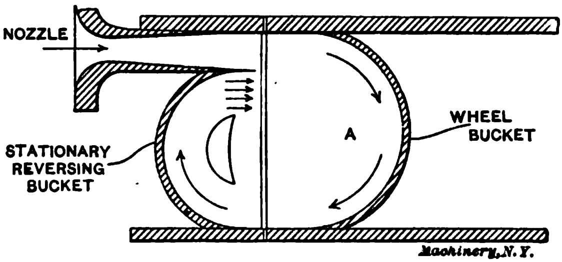

Fig. 26. Nozzle and Bucket Construction of the Terry Turbine

Fig. 26. The steam escaping from the nozzle strikes one side of the bucket, and is reversed in direction as shown. Leaving the opposite side of the same bucket it then enters the stationary or reversing

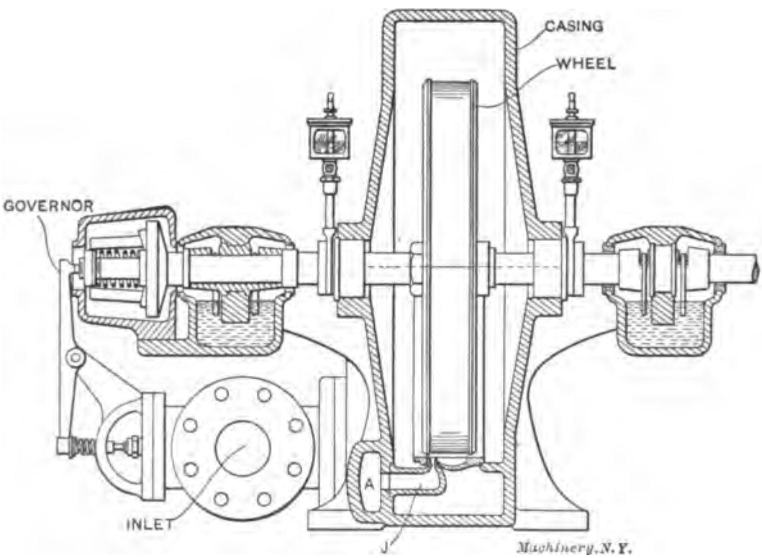

Fig. 27. Section through a Terry Steam Turbine

bucket and is directed back again into another bucket of the same wheel at a point adjacent to the nozzle. This operation is repeated as many times as necessary for the complete utilization of the available energy in the steam, its velocity being extracted successively in each

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reversal or stage. By means of this arrangement, the peripheral velocity may be reduced to about 250 feet per second, which corresponds to a speed of 2500 revolutions per minute for a 24-inch wheel.

Steam is thrown in a jet tangential to the circumference of the wheel (see *J*, Fig. 27), so that side thrust is avoided. Increased power

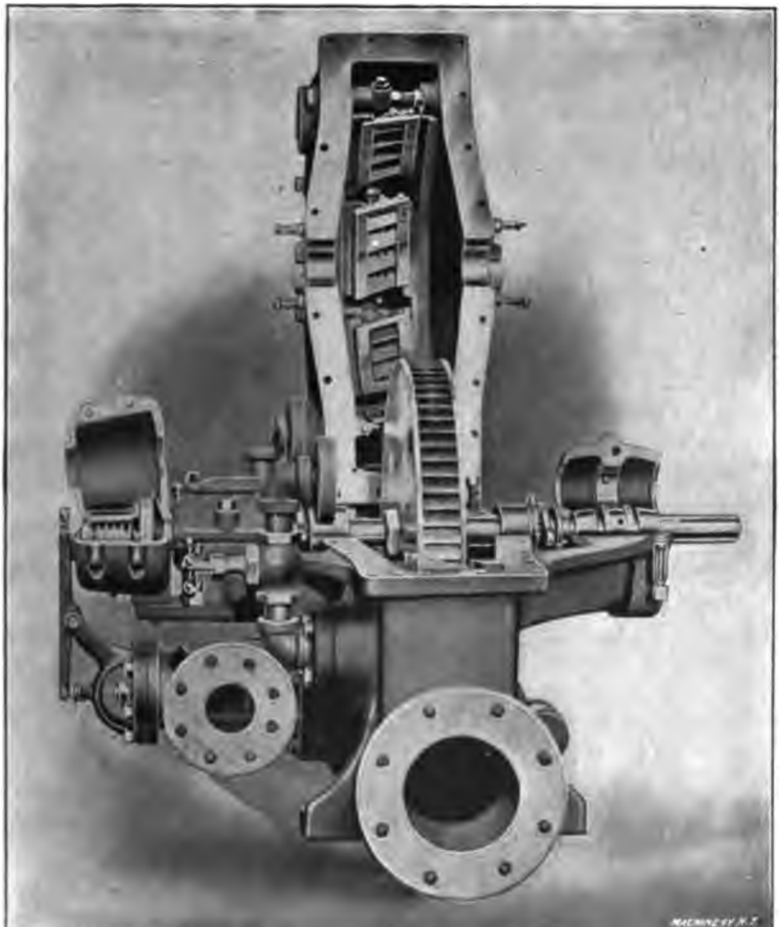

Fig. 28. General View of the Terry Steam Turbine, showing how Casing is parted Horizontally

for a wheel of given diameter is obtained by providing additional nozzles and reversing chambers in the casing, each nozzle being supplied with live steam from the annular space *A*. When only a partial load is to be carried, one or more of the nozzles may be turned off by hand-valves, in order to retain full-load efficiency.

The single-stage Terry turbine is shown in section in Fig. 27, and illustrates the relative position of the principal parts. The construc-

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tion is such that the casing and bearings are parted horizontally, as shown in Fig. 28. The nozzles enter the side of the casing as indicated in Fig. 27, while the reversing buckets are bolted to the inside of the casing around the circumference of the wheel as shown in the raised cover in Fig. 28. The reversing buckets are usually grouped in sets of four, each group being supplied with a separate jet of steam. The wheel and shaft are of steel, tested to safely withstand a speed 50 per cent in excess of the normal rating. The governor is of the fly-ball type, mounted directly upon the turbine shaft, and controls a throttle-valve of special construction.

For condensing service, the two-stage turbine is used for all except the smaller sizes. This turbine is shown in section in Fig. 29. After the steam has passed through the high-pressure stage, it enters the

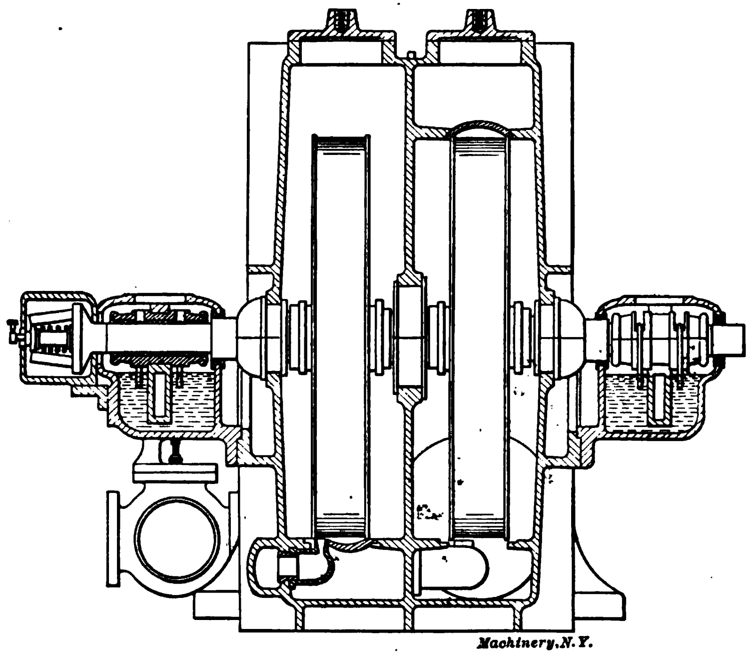

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Fig. 29. Two-stage Terry Turbine

second stage through nozzles and reversing chambers arranged similarly to those in the first stage. This turbine is often used direct-connected to dynamos, blowers, and centrifugal pumps, one of the most successful uses being in connection with the latter for boiler feeding under high pressure. Electric generating sets are made in sizes from 5 kilowatts capacity, running at 4000 R. P. M., to 300 kilowatts at 1250 R. P. M.

The Bliss Turbine

The Bliss turbine is of the same general type as the Sturtevant and Terry turbines, and is shown in section in Fig. 30. The casing and

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steam chamber of the turbine are cast in one piece, and the nozzle and reversing chambers bolted to it as shown. The wheel, in the smaller sizes, consists of a single steel casting or forging, the partitions separating the buckets being inserted and held in place by three steel bands shrunk on the face of the wheel. The general form of the buckets, to-

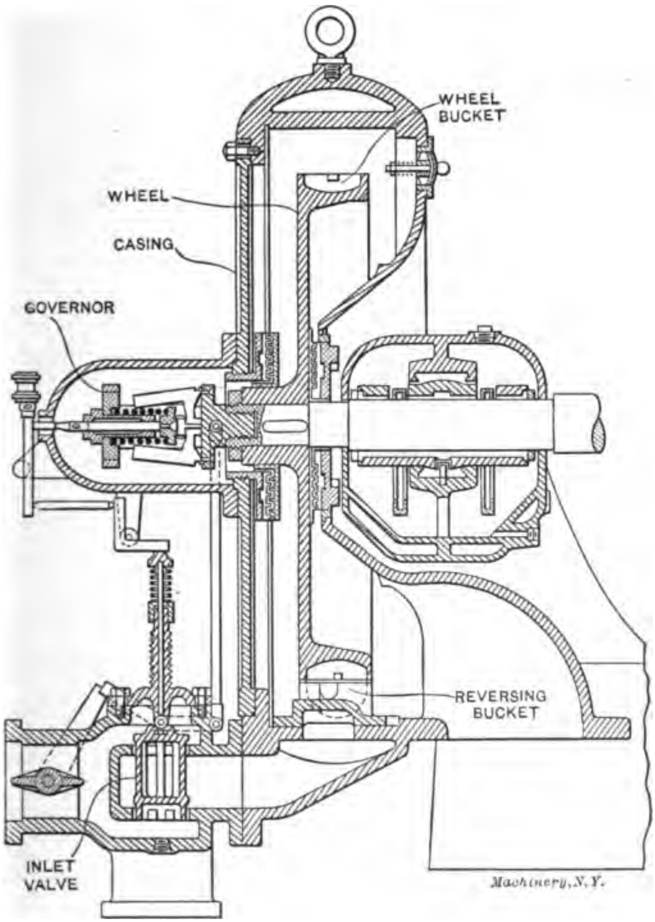

Fig. 30. Section through a Bliss Steam Turbine

gether with their construction, is shown in plan and section in Fig. 31. These turbines are made in sizes ranging from 10 to 600 horsepower.

The Kerr Turbine

The Kerr turbine is of the compound impulse type, and is usually built with from two to eight stages. The section shown in Fig. 34 illustrates the general construction of this machine and the principle upon which it operates. The buckets are of the double cup variety

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and are inserted like saw teeth in the wheel disk. Front and side views of a bucket are shown in Fig. 32, and a shaft with six disks in Fig. 33. The particular form of this bucket gives a nearly complete reversal of the jet of steam, which results in a high efficiency. The nozzles are in the plane of revolution of the wheel, being screwed into

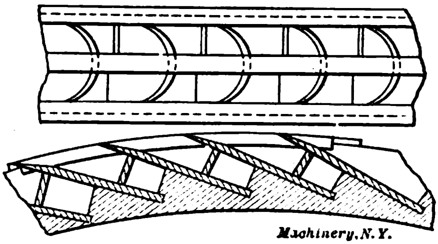

Fig. 31. Construction of Buckets of the Bliss Turbine

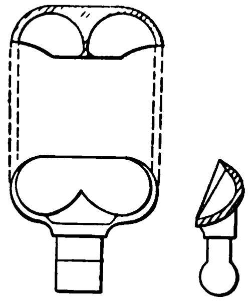

Fig. 32. Buckets of the Kerr Turbine

the stage partitions, and discharging jets of steam upon the wheel buckets as indicated in Figs. 34 and 35.

Referring to Fig. 34, it will be seen that the body of the turbine is made up of steam and exhaust end castings bolted to a cylindrical shell, which contains, in this case, five stage partitions or nozzle diaphragms. In the chambers thus formed are located the wheel disks, each having a row of double buckets around its periphery as shown in Fig. 33. Steam, in passing from one stage to the next, is thrown

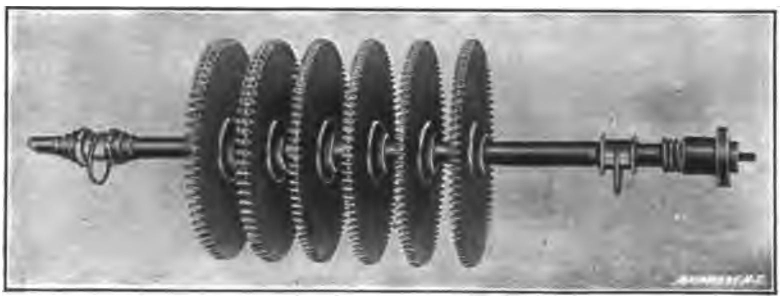

Fig. 33. Shaft of the Kerr Turbine, with Six Disks

against these buckets in tangential jets by the nozzles, which are best shown in Fig. 35.

Starting at the right in Fig. 34, the steam flows through a series of nozzles impinging upon the buckets of the first wheel, then passes through another series of nozzles into the next compartment, where the same action takes place upon the second wheel, and so on to the exhaust outlet at the left. By dividing the drop in steam pressure into several stages, the velocity is lowered sufficiently to secure a reasonable efficiency. As the velocity drops, the size of nozzles and buckets is increased to accommodate the increased volume.

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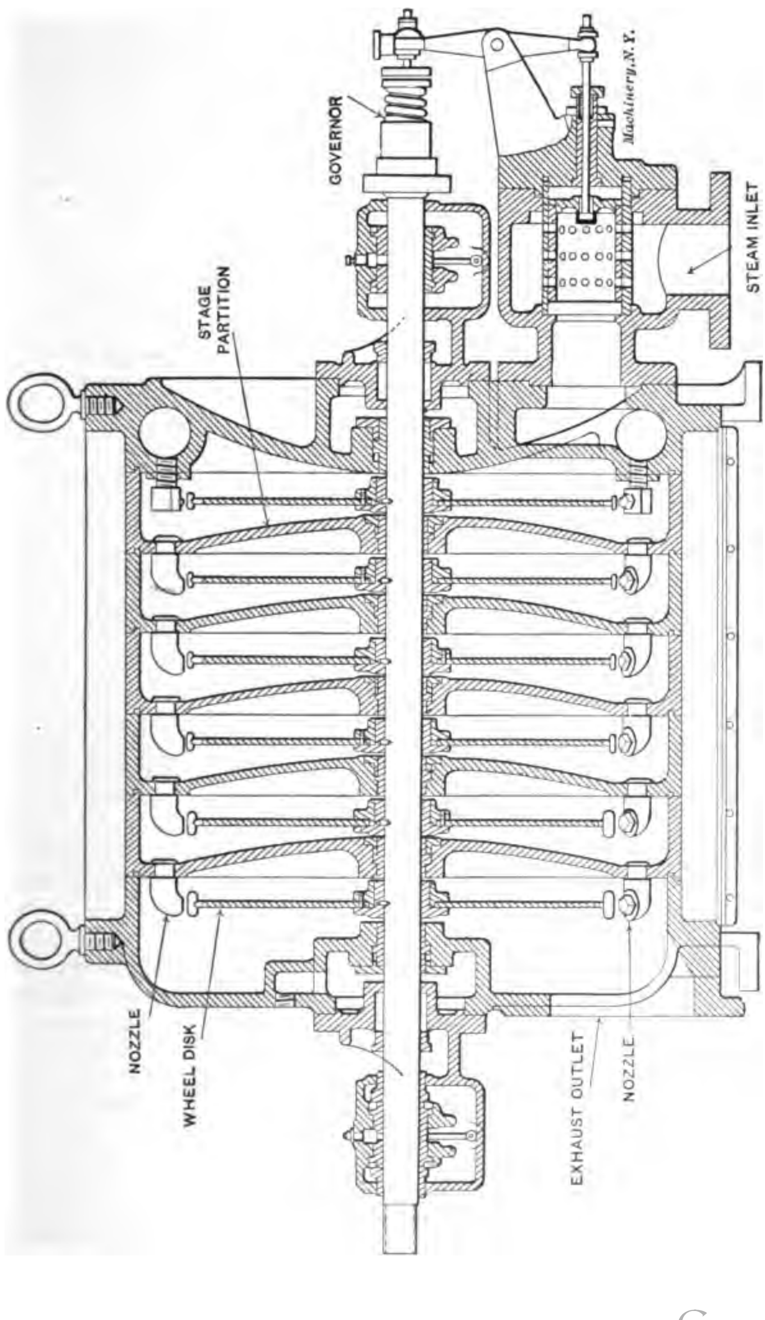

Fig. 34. Section through the Kerr Turbine

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Connection between the sections is made by means of "tongue-and-groove" joints packed with wicking and drawn together by means of through bolts. The nozzles are of steel, screwed into a nozzle body which in turn is riveted into the diaphragm casting. The buckets are drop forged from steel and are secured to the wheel disks by means of dove-tail slots, into which the shanks are inserted and riveted. The governor is of the centrifugal type mounted on the end of the shaft and attached to a valve in the inlet pipe as shown. This turbine is made both vertical and horizontal in form, one of the latter being

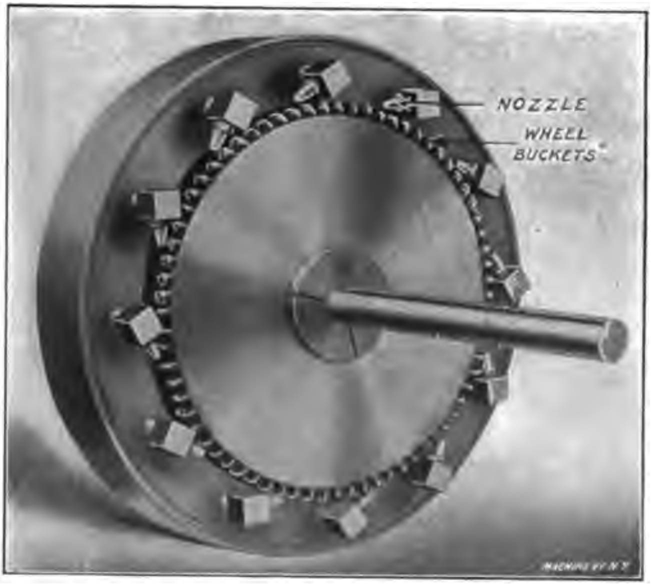

Fig. 35. Wheel and Nozzles of the Kerr Turbine

shown in Fig. 36. It is adapted to the various purposes for which turbines are used, and is made in sizes ranging from 10 to 300 horse-power.

The Rateau Turbine

The Rateau Turbine is a compound impulse turbine of the multi-cellular type, and is shown in section in Fig. 37. The principle upon which it operates is best explained by reference to the diagram in Fig. 38, which shows a portion of the nozzles and wheels of a three-stage turbine. In this figure the stationary nozzles are indicated by the letter *N* and the moving wheels by *W*, the latter revolving in separate compartments not shown in the engraving.

In operation, steam enters through the first set of nozzles at the left and impinges on the blades of the adjacent wheel as indicated by the arrows. It then passes through the next set of nozzles or guide vanes in a similar manner, and so on through each compartment until the exhaust space is reached. In Fig. 37, *A* is the steam inlet shown at

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the left end of the rotor, and *B* the exhaust space at the right. Nozzles and wheels are indicated by the letters *N* and *W*, respectively.

An interesting feature in connection with this turbine is the arrangement of the nozzles or guide vanes with reference to the number of openings in the different diaphragms. In the first one there are but few openings, arranged in three or four groups equally spaced around the periphery. The second diaphragm contains a greater number of openings to care for the increased volume of steam, due to its expansion as it passes from stage to stage. As the steam passes through the wheels the effect of rotation is to carry it along a short distance before discharging into the next chamber. For this reason each successive set of guide vanes is placed somewhat in advance of the one before it, in addition to increasing the number of openings. This arrangement is continued until finally the vanes extend entirely around the periphery of the diaphragms.

The wheels used in this machine consist of a series of flanged steel disks, upon the periphery of which the vanes are riveted. These are

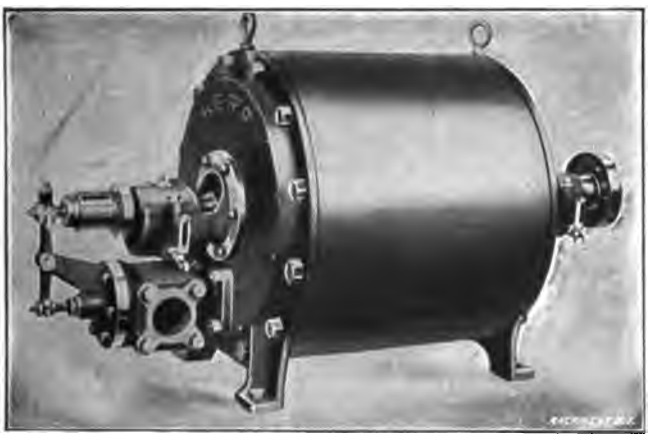

Fig. 36. Kerr Turbine of the Horizontal Type

strengthened by surrounding them with a steel band which serves to maintain an equal spacing and give them rigidity. Each wheel is arranged to revolve in a separate chamber formed by the diaphragms already mentioned and shown in Fig. 37. Since the spaces in each group of nozzles or distributors are located with reference to those in the adjacent diaphragms, as already described, the steam leaving one moving wheel enters directly into the following distributor without shock or loss of kinetic energy. On account of the progressive expansion of the steam, the vanes are much longer at the exhaust than at the admission end, as indicated in Fig. 37.

The speed is controlled by a governor of the centrifugal fly-ball type located at the end of the shaft, and driven by worm-gearing running in oil. The governor controls the admission of steam by means of a balanced valve in the supply pipe.

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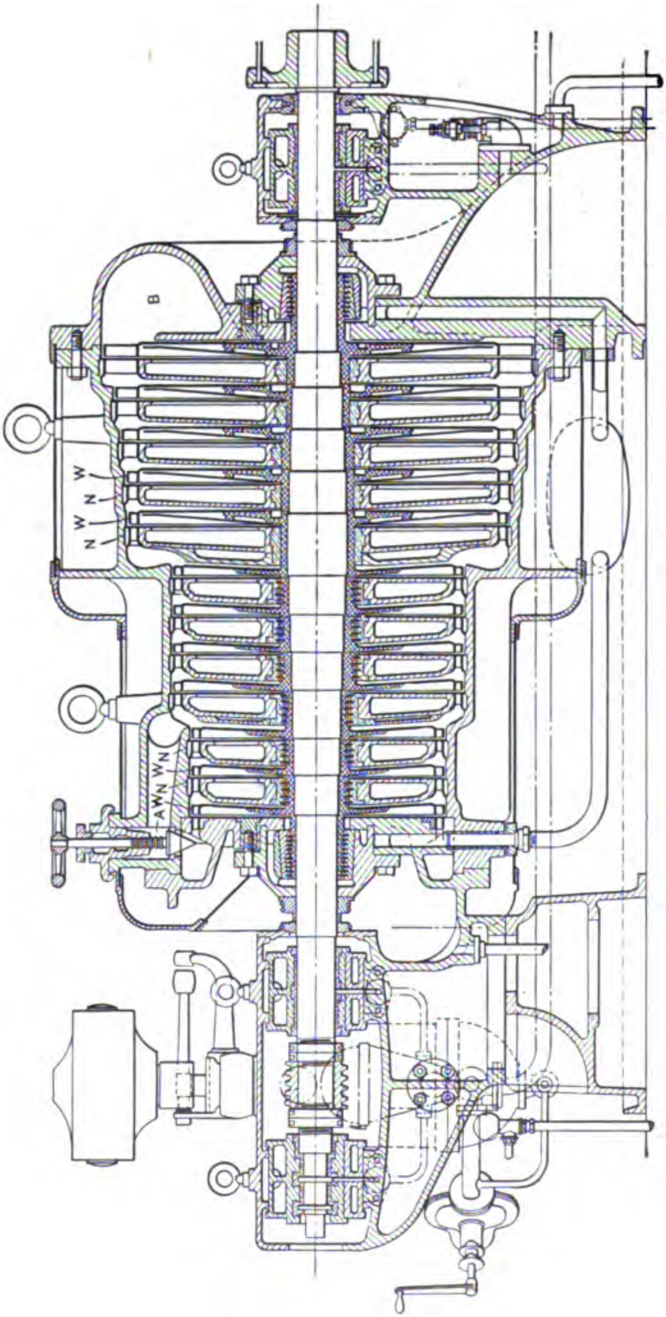

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Fig. 37. Section through the Rateau Turbine

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The Curtis Turbine

The Curtis turbine is of the compound impulse type, shown diagrammatically in Fig. 13. It is made both horizontal and vertical in form, depending upon the size. Generating sets ranging from 7 to 300 kilowatt capacity are of the former design, while the large units for central station work are of the vertical type on account of certain mechanical advantages to be mentioned later.

The general principle of operation is as follows: After leaving the nozzle, the steam passes successively through two or more lines of vanes on the moving element or rotor, which are placed alternately with reversed vanes on the stationary element. In passing through the stationary and moving elements in this manner the velocity acquired in the nozzle by expansion is largely taken up by the moving element.

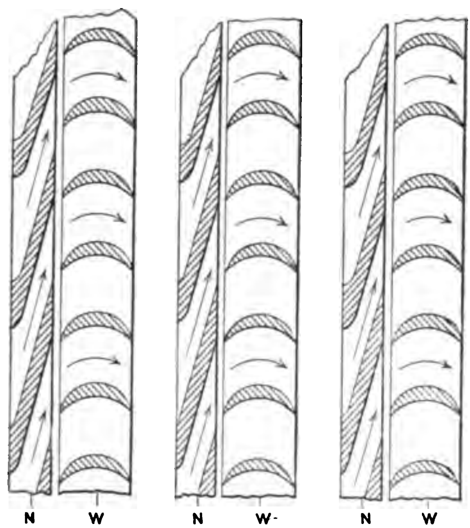

Fig. 38. Diagrammatical View of Nozzles and Wheels of the Rateau Turbine

Thus the steam is thrown against the first set of vanes of the moving element or rotor, and then rebounds alternately from moving to stationary vanes, until it is brought nearly to rest at the exhaust end. By this means a high steam-velocity is made to impart motion to a comparatively slow-moving element. This operation may take place in a single stage, but it is more common to make use of a number of stages with varying numbers of stationary and moving vanes in each stage.

A sectional view of a two-stage horizontal machine is shown in Fig. 40, the more important parts being indicated on the engraving. It will be seen, upon examination, that each wheel carries two sets of vanes, with a stationary set between them. This is shown more clearly in Fig. 41, which is an enlarged detail of the lower edge of the dia-

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phragm and wheel. Steam first passes through the nozzle from the steam chest against the first set of vanes on the first wheel, then through the stationary vanes which give it the proper direction for impinging on the second set of vanes on the same wheel. This admits the steam to the second compartment and completes the first stage of the operation. The second stage is precisely the same as the first, after which the steam passes into the exhaust outlet.

A detail of the blade or vane construction and the method of attaching the same to the periphery of the wheel is shown in Fig. 45. The buckets themselves are dove-tailed into a steel rim which in turn is bolted or riveted to the wheel disk as shown in Fig. 40.

In the case of large machines the vertical type (see Fig. 43) is usually preferred for the following reasons: The relative positions of

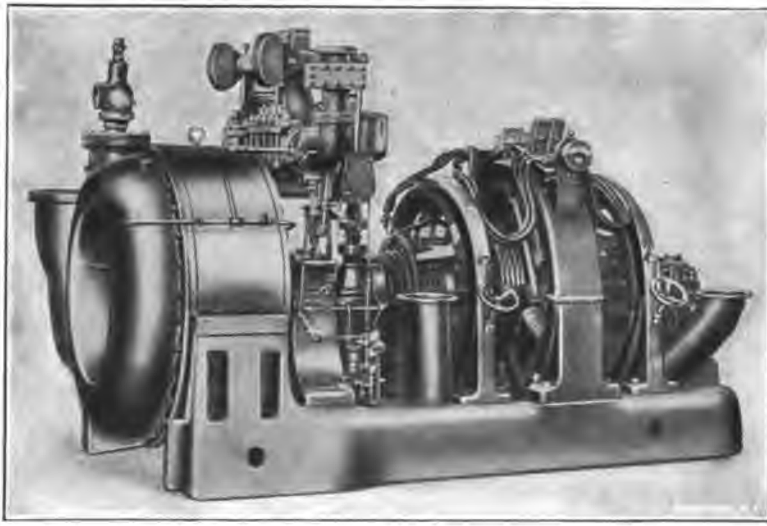

Fig. 39. Horizontal Generating Set with Curtis Turbine

the moving and stationary parts are fixed by the step-bearing at the bottom of the shaft; the main bearings are relieved from strain, and deflection of the shaft is eliminated; and the turbine structure forms a support for the generator, thus reducing the cost of foundations and producing a saving in floor space.

The turbine shown in Fig. 43, with an electric generator mounted on top of it, is of the four-stage type, and exhausts through the base into a condenser. The casing *K* is of cast iron, and is divided vertically into four parts for all sizes up to 3000 kilowatts, and into six parts for 5000 kilowatt capacity and larger sizes. It serves to hold the stationary buckets or intermediates, and also to support the diaphragms which separate the different stages.

The operation of this turbine is practically the same as that of the horizontal type. Steam enters from the governor valve *C*, by way of

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the passage *E*, and passes through the first row of revolving buckets, then through a set of intermediate buckets *X*, and then through the second row of moving buckets on the first stage wheel; and in the same manner through the nozzles and buckets of the four stages in succession. It will be noticed that the buckets and nozzles increase rapidly in size in succeeding stages, as the pressure falls, and the volume of steam increases.

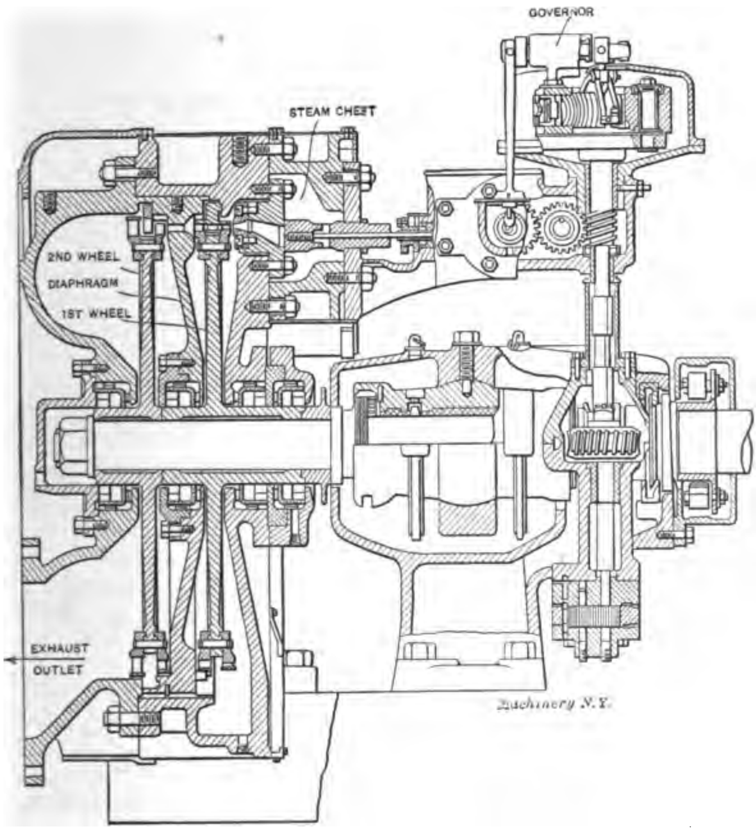

Fig. 40. Section through Two-stage Curtis Turbine

In designing this turbine, the parts are so proportioned that the steam gives up approximately one-quarter of its energy in each of the four stages. The governor is of the centrifugal type and is located at the upper extremity of the shaft. Its motion is transmitted by the rod *A* to the hydraulic mechanism *B* which operates the steam admission valves *C*.

In addition to the governor, the turbine is equipped with an emergency stop which operates automatically in case of an excessively high speed. This consists of a ring placed in a slightly eccentric position

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around the shaft between the turbine and generator. The centrifugal strain of this ring at normal speed is overcome by suitable springs, but when the speed increases beyond a certain point, the centrifugal effect overcomes the spring and closes a stop valve in the main steam pipe. The automatic stage valve *J* is for increasing the overload capacity, and operates by connecting the first stage directly to a set of auxiliary second-stage nozzles, thus widening the steam belt and increasing the power developed. An exterior view of a vertical generating set of 1500 kilowatt capacity is shown in Fig. 44.

Reaction Turbines

The general principle upon which the reaction type of turbine operrates has already been briefly outlined in the first chapter of this

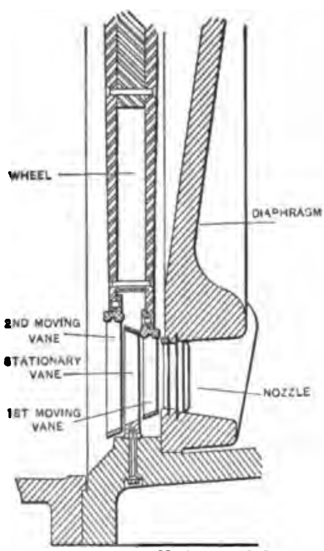

Fig. 41. Lower Edge of Diaphragm and Wheel of Curtis Turbine

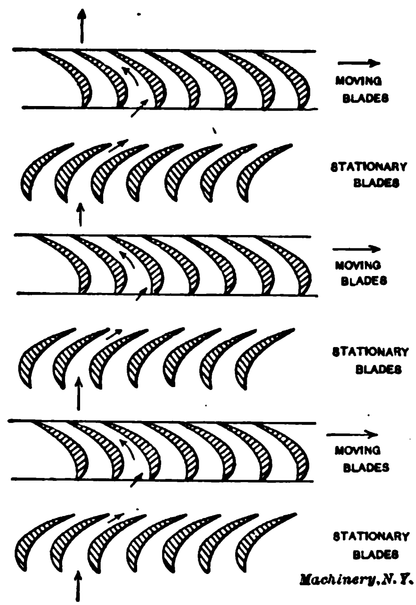

Fig. 42. Arrangement of Stationary and Moving Blades in Reaction Turbines

treatise. The reduction in pressure of the steam is subdivided into a large number of stages, and the steam expands in the moving as well as in the stationary elements. With this arrangement there is no violent change in pressure at any time, the reduction seldom exceeding three pounds in any one stage.

The essential parts of a turbine of this type consist of rows of stationary and moving blades arranged alternately as shown in Fig. 42, and through which the steam flows as indicated by the arrows. The steam is guided by the stationary upon the moving blades, expanding continuously throughout its passage through the turbine, and alternately gaining velocity and imparting it to the revolving blades, partly by impulse, but to a greater extent by reaction.

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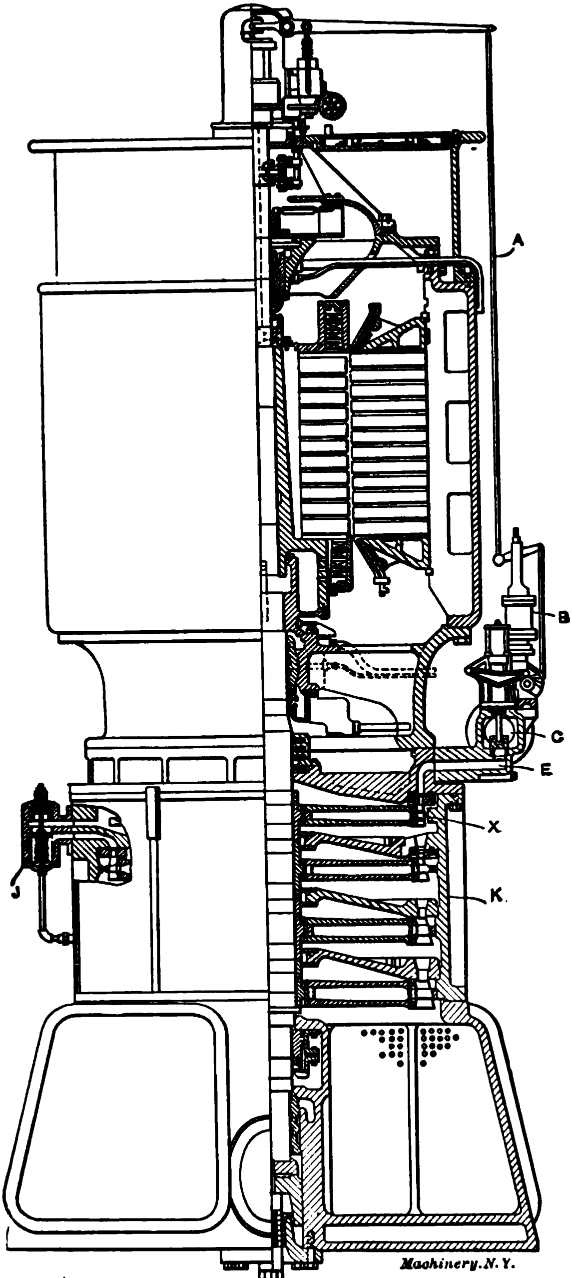

Fig. 43. Four-stage Curtis Turbine of Vertical Type with Electric Generator mounted on Top

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Parsons Turbine

As the principal reaction turbines are of the Parsons type, the action and general construction of this machine will first be described by

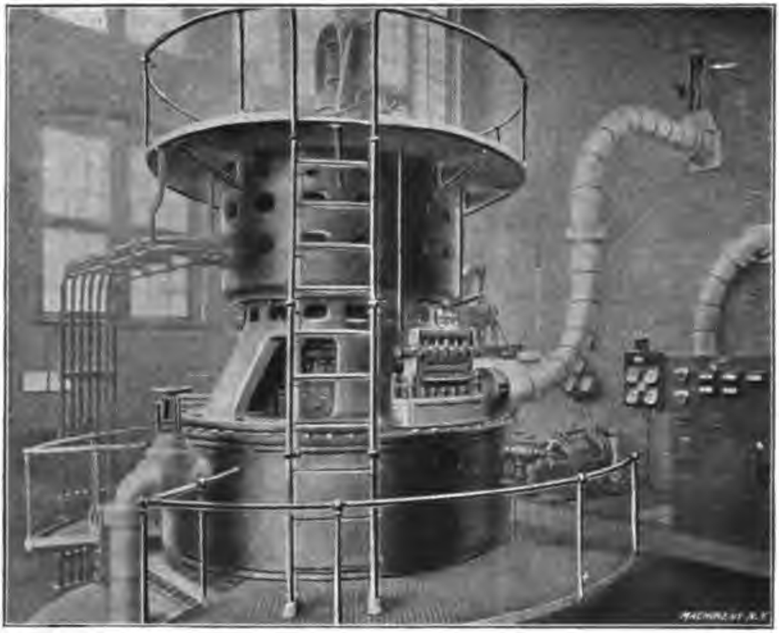

Fig. 44. General View of Vertical Type Steam Turbine and Generator Set

means of a diagram published by the Allis-Chalmers Co., and shown in Fig. 46.

This turbine consists of an outer casing or cylinder to which are attached the stationary blades, and a revolving cylinder or drum carrying the moving blades. The ends of the drum are extended in the form of a shaft and are carried by the bearings *A* and *B*. In operation, steam enters at *C*, then passes through the regulating valve *D* to the cylinder by way of the passage *E*. The direction of flow is now toward the left, passing through alternate rows of stationary and revolving blades, until the steam reaches the exhaust chamber *F* which connects either with the atmosphere or condenser as the case may be.

Fig. 45. Method of Attaching Blades of Curtis Turbine to Periphery of Wheel

In order to secure a uniform expansion and corresponding drop in

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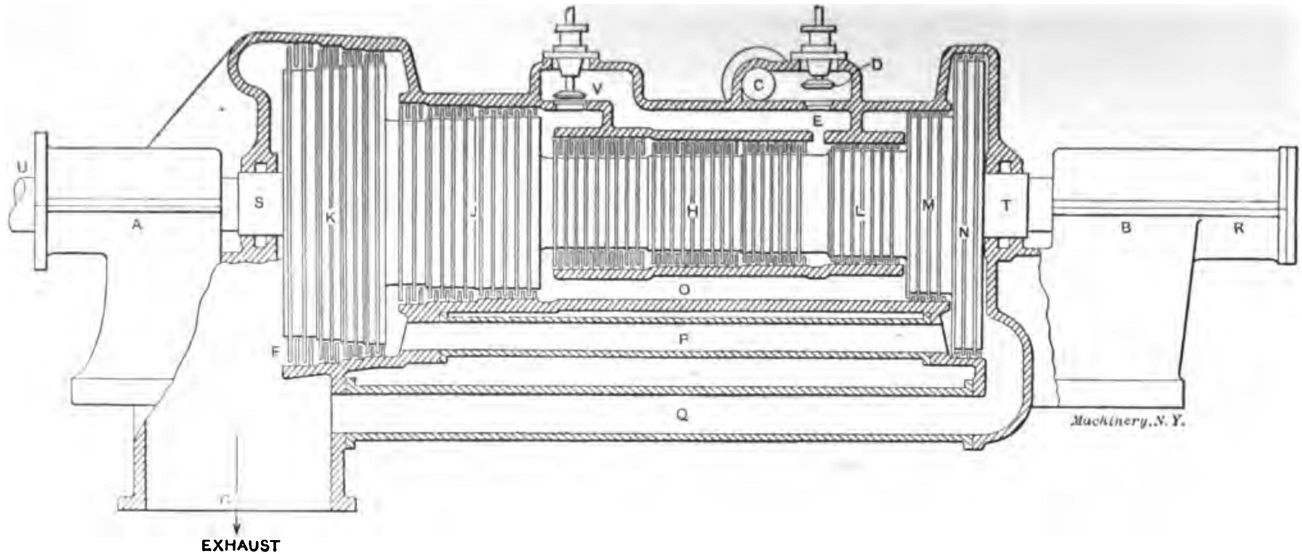

Fig. 46. Diagrammatical View of Parsons Type of Turbine

pressure throughout the length of the turbine, the volume of the spaces between the blades is gradually increased, by making the spindle or drum in three steps of different size as shown at *H*, *J*, and *K*, and by varying the length of the blades. At the beginning of each of the larger steps, the blades are made shorter than at the end of the preceding smaller step, the change being made in such a way that the correct relation of blade length to spindle diameter is secured.

In order to prevent end thrust on the spindle, due to the varying pressures and the difference in the size of the steps, "balance pistons" are used. These are shown

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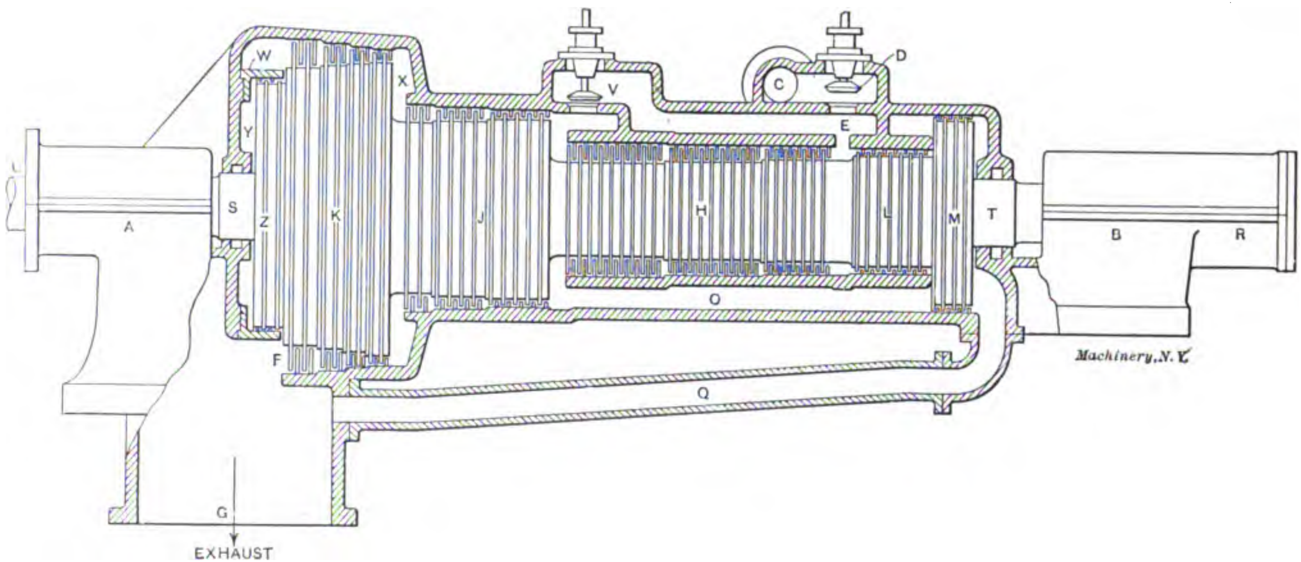

Fig. 47. The Allis-Chalmers Steam Turbine

at *L*, *M*, and *N*, which correspond in diameter to the steps *H*, *J*, and *K*, respectively. The parts *L*, *M*, and *N* are commonly called pistons, and leakage of steam past them is prevented by the use of packing rings which have the same appearance in the engraving as the blading. In order that each piston may have the correct pressure on both sides, the equalizing passages *O*, *P*, and *Q* are provided, connecting the pistons with the corresponding steps in the blading. Although the end thrust is cared for in this manner, the position of the spindle is fixed by an adjustable collar located at *R* within the bearing *B*. This is the construction of the original Parsons turbine.

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The Allis-Chalmers Turbine

The principle of the Allis-Chalmers turbine has already been described in connection with Fig. 46. In the larger sizes the balance piston *N* is omitted, and the piston *Z* substituted at the other end of the spindle, as shown in Fig. 47. In this construction, the equalizing pipe *P* of Fig. 46 is omitted, the pressure on the piston at *Y* being equalized with that in the third stage of the blading at *X* by means of passages through the spindle, not shown in the engraving.

The advantage of this construction is to eliminate piston *N*, Fig. 46, which on account of its large size is liable to become distorted when subjected to changing temperatures and pressures. By using the arrangement shown in Fig. 47 the same results are obtained as in Fig. 46, while the piston *Z* has a diameter considerably less than *N*.

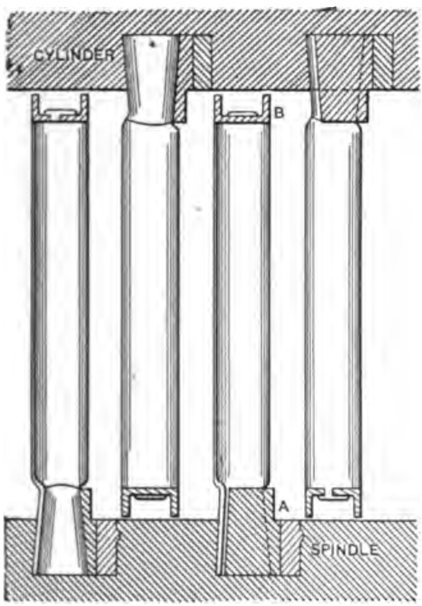

Fig. 48. Method of Constructing and Attaching the Blades

The construction of the blades and the method of attaching them to the cylinder and spindle are illustrated in Fig. 48. The root of the blade is dove-tailed to a foundation ring, which in turn is made in two sections and attached to the spindle or cylinder, as the case may be, in a similar manner. The tips of the blades are protected and held in place by means of a shroud of channel iron, shown in section at *B*. This is first rolled to the proper curvature, and then punched to receive the projecting tips of the blades, which are riveted in place. A view of the different rows of blading upon the spindle, together with the protecting shrouds, is shown in Fig. 49.

The governing of the turbine is effected by means of a balanced throttle valve *D*, Figs. 46 and 47, controlled by a governor through the medium of an oil relay system. Excessive speed is prevented by a separate safety governor which entirely closes off the steam supply when the speed reaches a certain point. Overloads are cared for by means of a governor-controlled by-pass *V* so arranged as to admit high-pressure steam to one of the later stages of the turbine when the load exceeds the normal capacity of the unit.

The Westinghouse-Parsons Turbine

The principles involved in the design of the Westinghouse-Parsons turbine are the same as those of the original Parsons turbine, which

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has already been described. It is, therefore, only necessary to show the general construction together with some of the more important details. A longitudinal section of a typical Westinghouse turbine is shown in Fig. 51. In operation, steam enters chamber *A* through the governor valve *V*, and passes to the left through the turbine blades to the exhaust chamber *B*. The balance pistons are shown at *P*, and the passages for equalizing the pressure upon corresponding pistons and drums at *E*.

Fig. 49. Rows of Blading of Allis-Chalmers Turbine

Fig. 52 shows a view of the rotor removed from the casing, and illustrates to some extent the method of construction. The rotor is built up of cast-steel drums which carry the blades, the latter being held in place by a special process of calking. The form of the blades and method of lashing the same are shown in Fig. 50. This construction is used in the case of all blades over two inches in length. Two types of bearings are used, depending upon the size of the machine. In the smaller sizes, running at a speed above 1800 revolutions per minute, a flexible oil-cushioned type of bearing is employed, but in the larger machines this is not found to be necessary. The bearings are so proportioned that the weight of the rotor is carried upon a film of oil without the use of forced lubrication under high pressure.

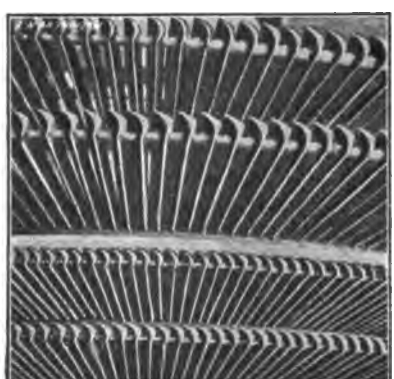

Fig. 50. Blading of Westinghouse Turbine

Speed regulation is secured by means of a fly-ball governor, shown diagrammatically in Fig. 53. The main admission valve *V*, Fig. 51, is actuated by an auxiliary piston *B*, Fig. 53, which in turn is moved

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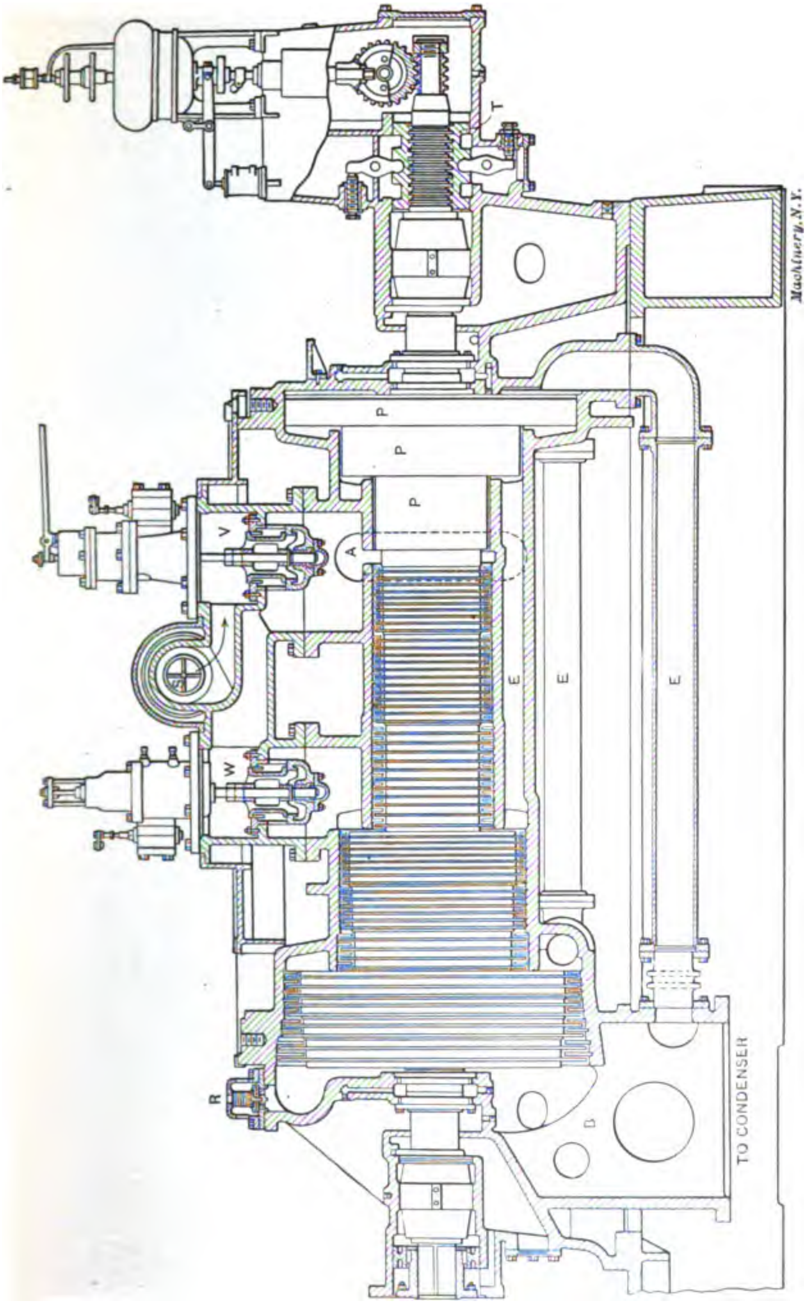

Fig. 51. Section of Westinghouse-Parsons Steam Turbine

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by the pilot valve *A* though the medium of high-pressure steam; *D* and *E* are fixed points, and *F* a floating fulcrum, the position of which is determined by the position of the governor balls, as indicated by the dotted lines. The vertical shaft *C* of the governor is driven from the

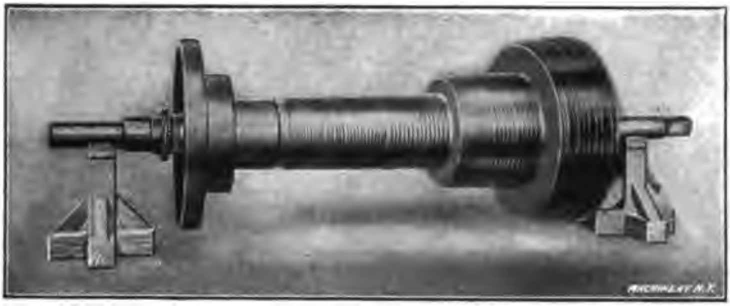

Fig. 52. Rotor of Westinghouse Turbine

main shaft by means of worm gearing, as shown at the right in Fig. 51. The connection with the admission valve *V* is not indicated in the engraving.

When in action, steam is admitted to the turbine in short puffs, at the rate of about 150 per minute, the governor operating to vary the

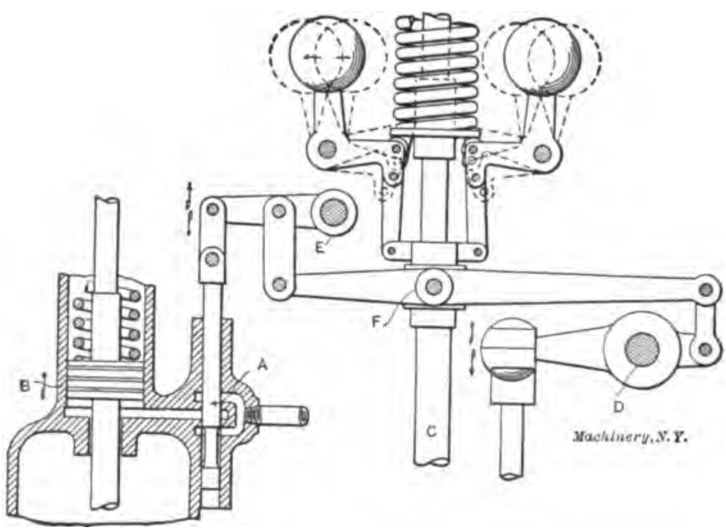

Fig. 53. Fly-ball Governor of the Westinghouse-Parsons Turbine

length of steam admission in proportion to the load. The secondary admission valve *W* admits high-pressure steam to the intermediate barrel in case of overload or when running non-condensing. Turbines of all sizes are provided with an automatic speed-limit governor for

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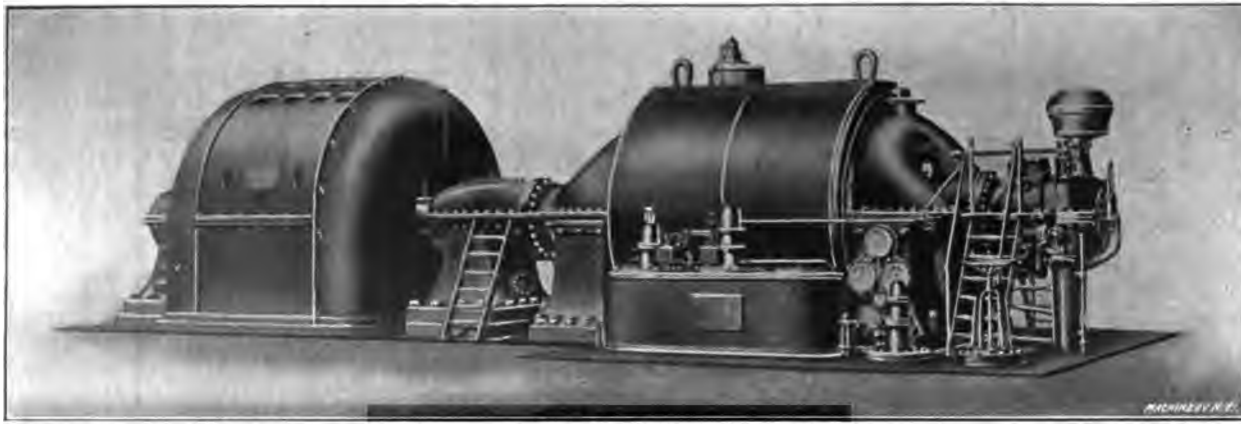

Fig. 54. Westinghouse Steam Turbine with Generator

shutting off the steam supply when the speed reaches a certain point above the normal.

Machines of this type are in use in sizes ranging from 300 to 7500 kilowatt capacity. In meeting the demand for still larger units, a modified Parsons type has been developed in order to reduce the bulk of the machine. This is known as the Westinghouse double-flow turbine, and is employed in the largest power station work. An exterior view of the standard turbine, together with an inclosed generator, is shown in Fig. 54.

The types described and illustrated in the present chapter may be considered as representative of practically all the more important types of steam turbines made, and while constructional details may differ in other designs, the same principles are involved and applied in a similar manner. In Germany, especially, a great many designs of different types have been made, but as no new principles are involved, it seems unnecessary to dwell upon the minor constructional details of these machines. In the next chapter, the commercial aspect will be considered.

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CHAPTER III

STEAM TURBINE ECONOMY

Under the head of steam turbine economy are comprised the subjects of steam consumption, effect of condensing, over and under loading, efficiency, etc. The study of these subjects is of value in comparing the action of a turbine with that of a reciprocating engine.

Steam Consumption

It may be stated, in a general way, that when operated at full load and under the most favorable conditions in each case, there is very little difference in the economy between the best types of reciprocating engines and the turbine. When compared with the single valve high-speed engine, in sizes below 500 to 700 indicated horsepower, the turbine may be made to give rather better economy, but if the four-valve compound engine is used, the results will, in general, be reversed. With engines of the best type, ranging from 1500 to 2500 indicated horsepower there is very little difference in results between the reciprocating engine and the turbine. With machines of 4000 to 5000 horsepower and above, the advantage seems to be with the turbine.

The water-rate of a reciprocating engine is commonly expressed in pounds per indicated horsepower (I. H. P.) per hour, as already explained in MACHINERY's Reference Series No. 70, "Steam Engines." In making a test for the water-rate or steam consumption, the indicated horsepower of the engine is computed from an indicator diagram, and this divided by the total weight of dry steam supplied to the engine per hour will give the water-rate. Sometimes the water-rate per *delivered* or *brake* horsepower (B. H. P.) is given. In this case the horsepower delivered by the engine is measured directly by an absorption dynamometer, and this is used in place of the indicated horsepower in making the computation.

It is evident that the indicated horsepower of a turbine cannot be determined, owing to the principle upon which it operates. For this reason its capacity is either expressed in brake horsepower, which may be measured as above, or, when connected with an electric generator, the output in kilowatts is commonly determined. In making a comparison of the steam economy of a turbine and engine, their operation should be reduced to a common basis; and as the delivered or brake horsepower is what determines the *practical* efficiency of any type of motor, this seems to be the rational basis for comparison.

The ratio of the brake horsepower to the indicated horsepower, $\frac{\text{B. H. P.}}{\text{I. H. P.}}$, is called the mechanical efficiency. Hence, if the mechanical efficiency of an engine, or of a class of engines, is known, the delivered horsepower may be found by the equation

B. H. P. = I. H. P. × Mechanical efficiency.

Again, if an engine is used to drive an electric generator, the delivered horsepower may be found from the electrical output in kilowatts, if the efficiency of the generator is known. For example:

Kilowatts × 1.34 = Electrical horsepower,

and this divided by the efficiency of the generator will give the delivered horsepower of the engine.

In the absence of more exact data, the following average efficiencies may be used when making comparisons.

TABLE OF EFFICIENCIES OF ENGINES AND GENERATORS

Compound Corliss Engines, Large Size	0.95.
Compound Engines, Medium Size	0.92.
Simple Engines, High-Speed	0.90.
Alternating-Current Generators, 3000 K.W	0.96.
Alternating-Current Generators, 500 K.W	0.94.
Direct-Current Generators, 3000 K. W	0.95.
Direct-Current Generators, 500 K. W	0.93.

Example: A compound engine of 2000 I. H. P. has a total steam consumption of 26,000 pounds per hour. How does it compare, in economy, with a turbine using a total of 40,000 pounds of steam per hour, attached to a 2000 K. W. alternating-current generator, running at full load?

Assuming from the table an efficiency of 0.95 for the engine, the B. H. P. is found to be 2000 × 0.95 = 1900; and the water rate, 26,000 ÷ 1900 = 13.7 pounds per B. H. P. If the generator is rated at 2000 K. W. and is operating at full load, the output in electrical horsepower is 2000 × 1.34 = 2680. Taking the efficiency of the generator as 0.95, the B. H. P. of the turbine will be 2680 ÷ 0.95 = 2821; and 40,000 ÷ 2821 = 14.2 pounds of steam per hour per B. H. P., from which a comparison of the steam economy of the two machines may be made.

It is sometimes desired to compute the steam consumption per indicated horsepower of a reciprocating engine which might replace a turbine operating under given conditions. For example, in the problem just solved, find the indicated horsepower and water-rate of a reciprocating engine which would replace the turbine and do the same amount of work, with the same *total* steam consumption. The first step is to find the brake horsepower required to drive the generator. This was shown to be 2821. Assuming an engine efficiency of 0.95, the indicated horsepower is 2821 ÷ 0.95 = 3000 (in round numbers), from which the water rate is found to be 40,000 ÷ 3000 = 13.3 pounds per I. H. P. per hour.

Effect of Condensing

The steam turbine is very sensitive to the effect of a vacuum—much more so than a reciprocating engine. This is due to the greater number of expansions obtained in the turbine, and can best be illustrated

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by use of a diagram. The full line in Fig. 55 shows a theoretical indicator diagram from an engine operating with four expansions. Fig. 56 represents a diagram from another engine having a cylinder of the same diameter, but twice as long. This takes the same amount of steam per stroke, but expands it eight times, on account of its increased volume.

Suppose that in the case shown in Fig. 55, the back pressure be lowered a given amount by the use of a condenser, as shown by the

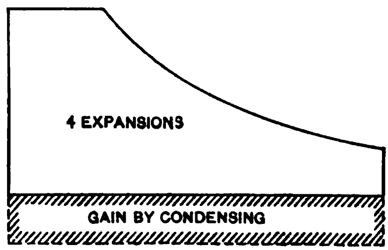

Fig. 55. Gain by Condensing when the Ratio of Expansion is 4

dotted line. The gain in work per stroke will evidently be indicated by the shaded portion at the bottom of the diagram. Now let the back pressure be reduced a like amount in the case in Fig. 56. In this case the gain is twice as great as in Fig. 55, owing to the greater length of the diagram. The best types of compound engines rarely have more than ten or twelve expansions, while a steam turbine may easily expand the steam one hundred times or more. Hence, under

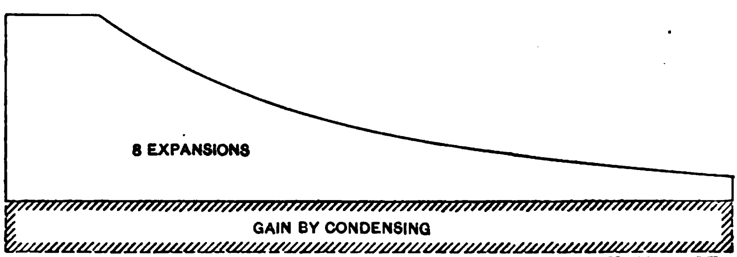

Fig. 56. Gain by Condensing when the Ratio of Expansion is 8

the above conditions, the relative effect of adding an inch to the vacuum will be from eight to ten times as great in the case of the turbine as with the engine. In addition to this, there is a still further gain due directly to the greater expansion of the steam.

On account of the excessive cylinder volumes and large valve areas required, it is not customary to release the steam from the cylinder below a pressure of about 6 pounds absolute, and 10 pounds is more common. For example, one pound of steam at a pressure of 100 pounds absolute, has a volume of 4.3 cubic feet. If expanded to a pressure of 1 pound absolute, which corresponds to a 28-inch vacuum,

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the volume will become 330 cubic feet, and if expanded still more, to a 29-inch vacuum, it will be increased to 640 cubic feet. Turbines are constructed to work satisfactorily at these high degrees of vacuum and are operated at 26 to 28 inches in commercial plants, while tests are often run with a vacuum of 28 to 29 inches.

When steam is exhausted from an engine, the heat which it contains at release, due to its terminal pressure, is wasted, regardless of the condenser pressure. With a reciprocating engine the advantage of a high vacuum is limited to the effect of a lower back pressure, while with a turbine the number of expansions is increased, the terminal pressure lowered, and more of the heat transformed into useful work.

A pound of steam expanded with perfect efficiency from 150 pounds gage pressure to an average terminal pressure of 10 pounds absolute, gives up sufficient heat to perform about 155,000 foot-pounds of work. If expanded to 0.5 of a pound (29 inches vacuum), it is capable of doing 275,000 foot-pounds of work. If the first represents the performance of a compound condensing engine, and the second that of a turbine, the theoretical gain would be 275,000 — 155,000 = 120,000 foot-pounds of work per pound of steam used, in favor of the turbine. These are, of course, ideal conditions, and do not take into account certain practical considerations, such as cylinder condensation, in case of the reciprocating engine, and the relatively low efficiency of the turbine. This comparison does show, however, the advantage of the turbine over the reciprocating engine at low pressures.

Low-pressure Turbine

The condition above described has led to the use of the so-called low-pressure turbine, designed to take the exhaust steam from a reciprocating engine and expand it down to a condenser pressure of approximately 1 pound absolute (28 inches vacuum). This type of turbine is adapted to plants where the engines are run either non-condensing or condensing. In the former case, plants are often operated non-condensing because any saving effected by the use of a condenser would be more than offset by the interest and depreciation on the first cost of the condensing apparatus, and the expense of cooling-water, where it has to be purchased. In plants of this kind, the increase in economy by the use of a low-pressure turbine is often sufficient to more than offset the expenses enumerated above. The advantage of placing a low-pressure turbine between the engine and a condenser already in use, and reducing the terminal pressure by 5 to 10 pounds has already been described in principle, and is frequently carried out in practice, under suitable conditions, with gratifying results.

Effect of Load Variation

Another advantage of the turbine over the engine is the fact that it maintains a more uniform efficiency under extreme variations of load. This is of especial value in electric plants, both for railway work and lighting. While there is very little difference in the relative performance of engines and turbines between the limits of 50 per cent

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above and below their most efficient rating, tests show that the turbine will carry loads in excess of this better than the reciprocating engine, especially if it is of a type equipped with an overload by-pass. This makes it possible to operate a turbine normally within the range of its best efficiency, whereas an engine, made large enongh to carry the maximum load, must normally run somewhat under load, with a resulting loss of efficiency.

Turbine Efficiency

The thermal efficiency of a heat engine is found by dividing 33,000 (the foot-pounds of work per minute for one horsepower) by the heat required per minute per indicated horsepower, expressed as its equivalent in foot-pounds. This rule expressed in the form of an equation, is as follows:

$$\text{Thermal efficiency} = \frac{33{,}000}{H \times 778},$$

in which H = heat units used by the engine per I. H. P. per minute.

In the case of a reciprocating engine, the indicated horsepower is obtained from an indicator diagram. The heat units required per I. H. P. per minute are determined from the steam consumption as follows: Find from a steam table the total heat in one pound of steam at boiler pressure, and from this subtract the heat of liquid, above 32 degrees, in the condensed steam. This multiplied by the total weight of steam used per minute, and divided by the indicated horsepower of the engine, will give the heat units (T. U.) required per I. H. P. The heat energy may be expressed in its work equivalent, in foot-pounds, by multiplying the number of heat units by 778.

Example: An engine operating at an indicated horsepower of 600, uses 8400 pounds of dry steam per hour; the boiler pressure is 100 pounds gage; the temperature of the condensed steam is 98 degrees. What is its thermal efficiency?

The total heat in one pound of steam at 100 pounds gage pressure

$$= 1185 \text{ T. U.}$$

$$\text{Heat in liquid} = 98 - 32 = 66 \text{ T. U.}$$

$$\text{Heat used by engine per pound of steam} = 1119 \text{ T. U.}$$

Pounds of steam used per minute $= 8400 \div 60 = 140$. Heat used per minute $= 140 \times 1119 = 156{,}660$ T. U. Heat used per indicated horsepower $= 156{,}660 \div 600 = 261.1$ T. U. Substituting this in the formula for efficiency, we have:

$$\text{Thermal efficiency} = \frac{33{,}000}{261.1 \times 778} = 0.162 \text{ or } 16.2 \text{ per cent.}$$

In finding the efficiency of a turbine, the process is the same except that the brake horsepower, in which its capacity is measured, must be reduced to indicated or internal horsepower by dividing by an assumed mechanical efficiency based on the average efficiency of a reciprocating engine of approximately the same power.

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Suppose in the above case a turbine is substituted for the engine, and develops a brake horsepower of 550, the weight and initial pressure of the steam, and the temperature of the condensation remaining the same. What will be the thermal efficiency?

Assuming as an average a mechanical efficiency of 0.93 for a reciprocating engine of this size, the indicated horsepower is found to be $550 \div 0.93 = 591$.

The remainder of the computation is the same as that given for the reciprocating engine, except that 591 is substituted for 600.

Superheated Steam

Steam which has been heated to a temperature higher than that due to its pressure, is called superheated. It contains a greater amount of heat than is given by a steam table, depending upon the degree of superheat. Superheated steam gives a higher efficiency than saturated steam, but is not used to any great extent in reciprocating engines on account of the difficulty experienced in lubricating the cylinder at such high temperatures. Turbines, on the other hand, do not require lubrication in the steam chambers, as there are no rubbing surfaces; hence, in a steam turbine, it is possible to take advantage of the higher efficiency due to the use of superheated steam, and these machines are commonly operated in this way.

Effect of Superheat on Efficiency

From the definition of superheated steam, it is evident that the weight of steam consumed by an engine in a given time does not indicate the amount of heat used. As turbines are commonly operated with superheated steam, and reciprocating engines with saturated steam, it is evident that in order to make a proper comparison of the efficiencies of the two, the comparison should be made on the "heat-unit" basis. This method has already been described for the engine and turbine using saturated steam. When superheated steam is used, the additional heat contained in a pound of steam should be added to the total heat obtained from a steam table for the given pressure. This additional heat may be found by multiplying the degrees of superheat by the specific heat of superheated steam, which may be taken as 0.48.

For example, a pound of steam at 100 pounds gage pressure, with 150 degrees of superheat, contains $1185 + (150 \times 0.48) = 1257$ T. U. In calculating the efficiency of a turbine using superheated steam, the computations should be made as previously described, except that the item of superheat under the given conditions should be added to the total heat as noted above.

Effect of Superheat on Water-rate

For the same reasons as were mentioned in connection with efficiencies, it is evident that a distinction should be made in regard to the water-rate of engines or turbines using superheated steam. Data in regard to this are based largely on experiment, but for approximations it will be sufficiently accurate to allow a reduction in steam consump-

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tion of 8 per cent for each 100 degrees of superheat. That is, if an engine shows a water rate of 14 pounds per indicated horsepower—with saturated steam—the water-rate would drop to $14 \times 0.92 = 12.88$ pounds if the steam were superheated 100 degrees, or to $14 \times 0.84 = 11.76$ pounds with 200 degrees of superheat. When making a comparison of the steam consumption of an engine supplied with saturated steam, and a turbine using superheated steam, the results should be reduced to a common basis by use of the above factor.

Lubrication

It has been mentioned in connection with the use of superheated steam that no oil is required within the steam chambers of the turbine. This makes it possible for the condensed steam to be used repeatedly in the boilers without the process of purifying, which is necessary in the case of reciprocating engines. The amount of oil required for the main bearings is small, as it is the usual practice in large plants to circulate the oil through the bearings instead of applying it and allowing the surplus to be wasted.

Quietness of Operation

The quietness with which a turbine-generator operates depends upon its design. The high speed at which it runs tends to produce a roaring noise, which may be reduced by making the exterior of the rotating field as smooth as possible, and also by encasing the generator. When the latter method is resorted to, the generator must be cooled by an air blast through the space within the casing.

Care and Operation

In the care and operation of a turbine, the same general precautions are to be observed as with a reciprocating engine of the same size. Special care should be taken in warming up a turbine before starting, for unless all parts are brought to their proper temperature, distortion is likely to occur, which may cause interference of the moving parts. Before starting up, steam should be admitted slowly and allowed to blow through the turbine while it is standing idle. Then, when started, it should be brought to speed slowly, to avoid a sudden rush of water from the boiler, the same as with a reciprocating engine. While the turbine is warming up, the auxiliaries, which include the circulating pump, hot-well and dry-air pumps, and oil pump, should be started, in order.

When superheated steam is used, the turbine should be rotated slowly for some time before bringing up to speed, in order that all parts may reach their normal temperature without too sudden a change. When shutting down a turbine, it is a wise precaution to partly close the throttle before reducing the load on the generator, so that it can be easily controlled should there be any tendency to speed up and the emergency valve fail to work. After closing the throttle, the condensing apparatus should be shut off, the same as for a reciprocating engine.

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NUMBER 72

PUMPS AND CONDENSERS STEAM AND WATER PIPING

CONTENTS

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CHAPTER I

PUMPS

Pumps are used for various purposes in connection with power and heating plants, the most important use being for the feeding of boilers, for the return of condensation from heating systems, for tank and fire service, and as part of the condensing outfit. The action of a pump is best described by reference to one of the simplest types, known as the direct-acting steam pump. This pump is shown in elevation in Fig. 1 and in section in Fig. 2. The "water-end" is at the right, and consists of a cylinder *H*, a piston *G*, valves *V* and *W*, and airchamber *A*. The water piston is actuated by a steam piston *P*, attached to a common piston rod *R*, as shown. The steam piston moves in cylinder *C*, and is forced backward and forward by steam pressure, which is controlled by the slide-valve *E*, the same as in a steam engine. Motion is transmitted to the valve *E* by means of the piston rod through the bell-crank *F*. The inlet connection is at *S*, and communicates with the space *I* just below the lower valves *V*. The discharge is at *D*.

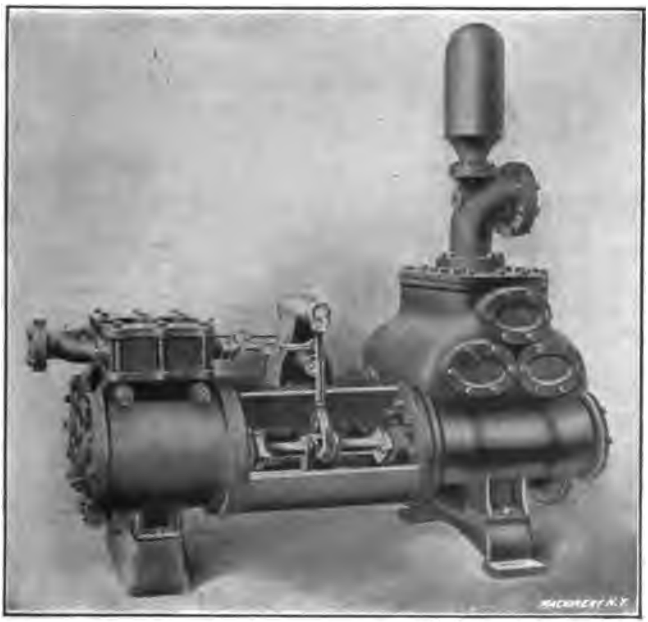

Fig. 1. Direct-acting Steam Pump

The action of the pump is as follows: Assume that the piston is moving toward the left, as indicated by the arrow; this causes a

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pressure in the left-hand end of the cylinder which raises valve *W* and allows the water to flow into the upper chamber, and thus outward through the delivery pipe *D*. In the meantime a partial vacuum is formed in the other end of the cylinder, which causes the valve *V* to lift, due to the greater pressure in the space *I*, and the cylinder space at the right of the piston is thus constantly kept full of water when the piston moves toward the left. At the end of the stroke the steam valve reverses, and the piston moves toward the right, forcing out the water in front of it into the delivery chamber, and drawing in a supply behind it for delivery at the next stroke, as already described.

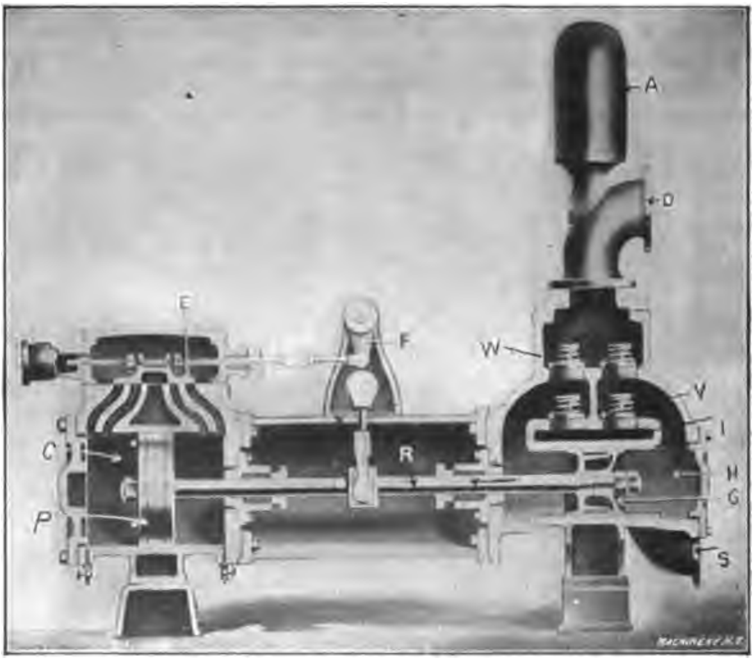

Fig. 2. Section of Direct-acting Steam Pump

The air-chamber *A* tends to equalize the pressure at the instant the piston changes its direction of travel, thus causing a steadier flow of water through the discharge pipe. This is brought about by the cushion of air which is compressed in the upper part of the chamber, and which exerts a momentary pressure after the piston stops. The water end of the pump above described is typical of the cylinder pump, whether driven by a steam piston or by other means. Centrifugal and rotary pumps differ in principle from the above, and will be described in detail later.

Suction is the term commonly employed to denote a lowering of the pressure within the inlet pipe below that acting upon the surface of the water with which the "suction pipe" connects. For example, let

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the suction pipe of a pump connect with a reservoir of water open to the atmosphere. If now the piston moves forward, a vacuum will be formed back of it which will at once be filled by the water which is being forced in through the suction pipe and inlet valves, due to the pressure of the atmosphere acting upon the surface of the reservoir.

A column of water, 1 inch square and 1 foot high, weighs 0.433 pound when at a temperature of 60 degrees F. The normal pressure of the atmosphere at sea level is 14.7 pounds per square inch. Hence, atmospheric pressure will raise water to the height of $14.7 \div 0.433 = 34$ feet. in round numbers, in a pipe connected with a perfect vacuum. From the foregoing it is evident that what is commonly known as suction is in reality the forcing of water under a higher pressure (atmospheric in most cases) into the cylinder, which is under a partial vacuum due to the forward movement of the piston.

In actual practice it is not possible to produce a perfect vacuum back of the piston owing to imperfections which allow the leakage of air into the cylinder. With the very best construction it is possible to reduce the pressure within the cylinder to about 2.5 pounds per square inch, leaving an unbalanced pressure of 12.2 pounds, which will raise a column of water in the suction pipe to $12.2 \div 0.433 = 28$ feet. The average pump in good working order will lift water by suction only about from 25 to 26 feet, with a fair degree of economy.

In cases where a pump takes its supply directly from the mains of a town or city water system, some means should be provided for equalizing the pressure, as this is constantly changing due to the water being drawn off at different points. When the water comes to the pump under varying pressure, an increase of pressure in the suction pipe is equivalent to a decrease in the pressure pumped against, and this condition is, therefore, likely to vary the speed of the pump, even when the head pumped against remains constant. This is especially noticeable in boiler feeding, where the pumps are set to run at a uniform speed against a constant pressure, thus maintaining the water line at a given point. If the speed of the pump varies, due to changes of pressure in the suction or supply pipe, the water level in the boilers is liable to fluctuate rapidly and must be carefully watched.

This condition is commonly overcome in two ways, one of which is to use a pressure reducing valve in the suction pipe of the pump, which maintains a constant pressure at this point; the other method is to employ a pump governor which maintains a constant speed under widely varying pressures. The effect of a fluctuating suction pressure is sometimes overcome to a considerable extent by throttling the supply by partially closing the valve and causing the pump to "draw" the water through it. The most satisfactory method, however, is the employment of a governor, which makes the action of the pump independent of the pressures either upon the suction or forcing side of the piston.

When pumping hot water, it is usually necessary to place the

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pump low enough for the water to flow into it by gravity. This is because water at high temperatures will break into steam under low pressures. Theoretically, water at a temperature of 200 degrees can be raised 8 feet by suction, but in practice it has been found safer to bring the water to the pump by gravity when the temperature approximates 190 degrees. A pump built for hot-water service also requires special packing for the valves and piston in the water end.

Pressure Head

The pressure against which a pump forces the water is usually expressed in "feet head." For example, a pump feeding a boiler against a pressure of 100 pounds per square inch is operating under a head of $100 \div 0.433 = 231$ feet, that is, each pound pressure per square inch against which the water is forced is equivalent to lifting a column of water 1 inch square and 2.31 feet high. From the above, it is evident that

pressure per square inch in pounds $\div$ 0.433 = head in feet, and
head in feet $\times$ 0.433 = pressure per square inch in pounds.

In determining the pressure head or total height to which the water must be raised, the distance must be taken from the surface of the water in the reservoir from which it is drawn to the point of discharge. The same power is required to raise water by suction as to force it, and the height of the pump above the water does not enter separately into the calculation at all, provided it is not more than 28 feet. This is made plain by a practical example. Assume that a pump is raising water by suction 18 feet, and discharging it at this elevation without forcing it at all, all the work being done on the suction side of the piston. When water is raised to this height by suction, the air pressure in the suction pipe is reduced to $14.7 - (18 \times 0.433) = 6.9$ pounds per square inch. This leaves an unbalanced pressure upon the other side of the piston equal to $14.7 - 6.9 = 7.8$ pounds per square inch. The effect is therefore, the same as if the pump were forcing the water against this pressure with the water flowing into the cylinder by gravity. To illustrate this, take a case where the water flows to the pump by gravity, and is raised to a height of 18 feet. Here the pressure per square inch against which the piston must work is $18 \times 0.433 = 7.8$ pounds, the same as in the case above. Hence it is evident that the work done by the pump is the same whether the water is raised a given distance by suction or forced to the same height by the pressure of the piston.

Friction Head

In what has been said regarding the pressure head required for raising water to a given height, or forcing it against a pressure, as in boiler feeding, no reference has been made to the resistance due to the friction of the water against the sides of the pipes. In computing the required power for operating a pump, and the pipe sizes in a boiler plant where the distances are short, no account is taken of this, but

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when water is moved long distances through pipes, this must be taken into consideration. For convenience in making computations, tables have been prepared giving the frictional resistance for pipes of different diameters and different velocities of flow of water. A portion of such a table is given herewith (see Table I) for purposes of illustration. More complete tables can be found in any engineer's handbook on hydraulics.

Table I gives the velocity in feet per second, and the friction head in pounds per square inch for pipes from 1 to 8 inches in diameter and

TABLE I. PIPE SIZES, CAPACITIES, VELOCITY AND FRICTION HEAD

Velocity in feet per second. Friction head in pounds per square inch per 100 feet

Gallons per Minute	1-inch		2-inch		3-inch		4-inch		6-inch		8-inch	
	Velocity	Friction Head	Velocity	Friction Head	Velocity	Friction Head	Velocity	Friction Head	Velocity	Friction Head	Velocity	Friction Head
25	10.2	19.0	....	....	....	....	....	....	....	....	....	....
30	12.3	27.5	....	....	....	....	....	....	....	....	....	....
35	14.3	37.0	....	....	....	....	....	....	....	....	....	....
40	16.3	48.0	4.1	1.6	....	....	....	....	....	....	....	....
45	....	....	4.6	2.0	....	....	....	....	....	....	....	....
50	....	....	5.1	2.4	....	....	....	....	....	....	....	....
75	....	....	7.7	5.8	....	....	....	....	....	....	....	....
100	....	....	10.2	9.5	4.5	1.3	....	....	....	....	....	....
125	....	....	15.8	14.9	5.7	2.0	....	....	....	....	....	....
150	....	....	16.3	21.2	6.8	2.8	....	....	....	....	....	....
150	....	....	17.1	28.1	7.9	3.8	....	....	....	....	....	....
175	....	....	....	....	9.1	5.0	4.5	1.0	....	....	....	....
200	....	....	....	....	11.3	7.8	5.1	1.2	....	....	....	....
250	....	....	....	....	13.6	11.2	6.4	1.9	....	....	....	....
300	....	....	....	....	15.9	15.2	7.7	2.7	....	....	....	....
350	....	....	....	....	....	....	8.9	3.6	4.0	0.5	....	....
400	....	....	....	....	....	....	10.2	4.7	4.5	0.6	....	....
450	....	....	....	....	....	....	11.5	6.0	5.1	0.8	....	....
500	....	....	....	....	....	....	....	....	5.7	1.0	3.2	0.2
750	....	....	....	....	....	....	....	....	8.5	2.2	4.8	0 5
1000	....	....	....	....	....	....	....	....	11.3	3.9	6.4	0.9
1500	....	....	....	....	....	....	....	....	....	....	9.6	2.1

100 feet in length. As the frictional resistance is proportional to the length, the friction head for any other length is easily found as follows: From Table I the friction head for a 4-inch pipe discharging 300 gallons per minute is 2.7 pounds per square inch. For a pipe 800 feet long this would be $8 \times 2.7 = 21.6$ pounds, and for a pipe 50 feet long, $0.5 \times 2.7 = 1.35$ pounds per square inch.

The friction heads given in Table I are for straight runs of pipe; when elbows and valves are introduced, the resistance is increased. In computing the friction head under these conditions it is sufficiently accurate to assume the resistance due to each elbow as increasing the length of the pipe 60 diameters, and the resistance due to each globe valve as increasing the length 90 diameters.

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"Slip" is the term used to denote the difference between the theoretical capacity of a pump and the actual, and is usually expressed as a percentage of the theoretical or calculated discharge. Slip is due partly to leakage around the piston and valves, but more especially to the results of too high speed. When a pump runs too fast, the piston speed is so high that the water cannot flow through the valves fast enough to completely fill the cylinder; hence the actual discharge is less than the theoretical. Another effect of high speed is its action upon the seating of the valves. These do not act instantaneously, but require a certain length of time to reach their seats when the piston reverses its direction. When a pump runs at high speed the piston will move a considerable distance while the valves are descending to their seats, and water will flow back into the cylinder from the discharge chamber, thus reducing the volume actually pumped at each stroke. The average slip in pumps of different kinds at medium speeds is given in Table II.

Pump Valves

The valves in the usual type of pump are carried by two plates or decks, the inlet valves being below the discharge valves, as shown in

TABLE II. PERCENTAGE OF SLIP IN PUMPS

Type of Pump	Percentage of Slip	Actual Discharge expressed as a Percentage of the Theoretical Value
Boiler feed pumps	20	80
Water works pumps	5	95
Small centrifugal pumps	65	35
Medium centrifugal pumps	45	55
Large centrifugal pumps	20	80

Fig. 2. The valves used in practically all pumps, except pumping engines, are of the flat disk type shown in Fig. 3, and consist of a ring of special material pressed into a metal casing or plate, which slides upon a bolt screwed into a bridge across the port opening, as shown. A conical spring is employed to hold the valve firmly to its seat, the spring being held in position by the head of the bolt.

In order to reduce the slip of a pump, it is customary to use several small valves instead of a single large one of equivalent area, and to secure a full port opening it is necessary for the valve disk to rise a distance equal to one-quarter of its diameter from the seat. From this it is evident that the travel of the valve and the consequent wear and jar is much less with disks of small size. For a quick-running pump for ordinary service the valves should not exceed 4 to 4½ inches in diameter, and their combined area should not be less than 35 per cent of the area of the water piston or plunger.

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Size of Suction and Delivery Pipes

The area of the suction pipe is based upon the velocity of flow through it, and may be found by means of the following formula:

$$b = \frac{a \times S}{V} \qquad (1)$$

in which

b = area of suction pipe in square inches,
a = area of piston or plunger in square inches,
S = piston speed in feet per minute,
V = velocity of flow through suction pipe in feet per minute. This velocity equals:

200 for 25 feet in length,
180 for 50 feet in length,
150 for 100 feet in length,
125 for 125 feet in length.

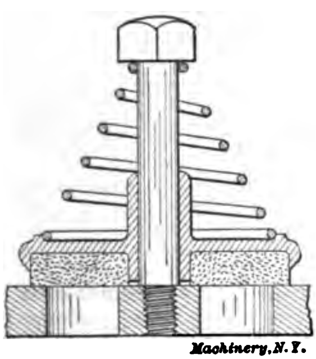

Fig. 3. Disk-type Pump Valve

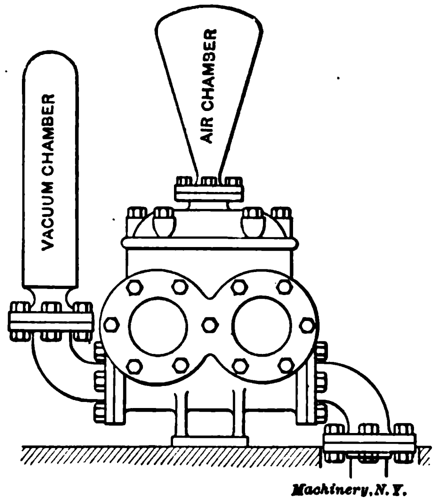

Fig. 4. Pump with Vacuum Chamber

These velocities allow for two or three elbows, a stop valve and a foot valve.

The area of the delivery pipe may be found by the same formula by substituting 300 for the value of V in all cases. This is because in the suction pipe the pressure acting to force the water through it is practically constant and never exceeds that of the atmosphere, hence any increase in frictional resistance due to a greater length of pipe must be allowed for by assuming a lower velocity of flow through it. In the case of the delivery pipe a constant rate of flow may be maintained by increasing the steam pressure or by using a larger steam cylinder.

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Speed

For pumps of usual construction, having water cylinders less than 10 inches in diameter, the best results are obtained with piston speeds of from 30 to 40 feet per minute for continuous operation. When the pump is only used occasionally for short lengths of time, the speed may be increased to 60 or 80 feet per minute without undesirable results. The speed of a pump is often given in strokes per minute instead of in feet, as the reversal of the piston at the end of the stroke is what is detrimental to the pump at high speeds. For elevator service and similar purposes, the maximum speed of a direct-acting pump should not exceed 60 strokes per minute, and for boiler feeding, it should be kept down to from 25 to 35 strokes.

Area of Steam and Water Cylinders

The steam cylinders of nearly all direct-acting pumps are of larger diameter than the water cylinders; as a rule they are from 25 to 50 per cent greater in diameter. In pumps employed for boiler feeding, the ratio of diameter of steam to water cylinder is usually about 1.25. In pumps used exclusively for low-pressure work, that is, for moving large volumes of water under low pressures, the ratio is less, and for high-pressure work it is considerably more. The equations given below will be found useful for proportioning the steam and water cylinders to meet different conditions.

$$P = \frac{p}{A \div a} \qquad (2); \qquad p = \frac{A \times P}{a} \qquad (3)$$

$$A = \frac{a \times p}{P} \qquad (4); \qquad a = \frac{A \times P}{p} \qquad (5)$$

in which

P = steam pressure per square inch,
p = water pressure per square inch (total head),
A = area of steam piston in square inches,
a = area of water piston in square inches.

The theoretical capacity of a pump in cubic feet per minute may be found by multiplying the area of the water piston in square feet by the piston speed in feet per minute, or by multiplying the piston displacement in cubic feet by the number of strokes per minute. To obtain the actual capacity these results must be corrected for slip. While the above results are obtained in cubic feet, they may be changed to other denominations by the use of the factors given below:

Cubic feet × 7.5 = gallons,
Cubic feet × 62 = pounds,
Gallons × 8.3 = pounds.

The power required for operating a pump may be found by either of the following equations, depending upon the data at hand.

$$\text{H. P.} = \frac{W \times H}{33{,}000} \qquad (6)$$

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$$\text{H. P.} = \frac{a \times p \times S}{33{,}000} \qquad (7)$$

$$\text{H. P.} = \frac{A \times P \times S}{33{,}000} \qquad (8)$$

in which

H. P. = delivered horsepower,
W = pounds of water pumped per minute,
H = vertical height to which it is raised, in feet,
A = area of steam piston, in square inches,
a = area of water piston, in square inches,
P = steam pressure, in pounds per square inch,
p = water pressure, in pounds per square inch,
S = piston speed, in feet per minute.

Equation (6) applies to any form of pump, as the power is based entirely upon the weight of water and the height to which it is raised; the piston areas and the pressures do not enter into the computation. Equations (6) and (7) are for short pipe connections and do not take into account the friction head. If the discharge is of considerable length, the power required to overcome the friction should be computed from data given in Table 1, and added to the results given by equations (6) and (7). Equation (9) may be used for determining the horsepower due to friction in the discharge pipe:

$$\text{H. P.} = \frac{F \times c \times V}{33{,}000} \qquad (9)$$

in which

F = friction head in pounds per square inch for the given length of pipe and velocity of flow through it,
c = area of pipe, in square inches,
V = velocity of flow through pipe, in feet per minute.

Air and Vacuum Chambers

Air chambers, as already stated, are used on pumps for the purpose of causing a steady discharge of water and allowing the pump to run at a higher rate of speed. The location and general form of an air-chamber is shown at *A* in Fig. 2. The air which it contains is compressed during each stroke. When the piston stops momentarily at the end of the stroke, the air expands to a certain extent, and tends to produce a gradual stopping of the flow of water, thus permitting the valves to seat easily without shock or jar.

In the case of single-cylinder boiler feed pumps, and those employed for elevator service, the volume of the air chamber should be at least three times that of the piston displacement. For duplex pumps it should not be less than twice the piston displacement of one of the pumps. In the case of high-speed pumps, this ratio should be increased to 5 or 6.

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The action of a vacuum chamber is the reverse of that of an air chamber. When the column of water in the suction pipe is once set in motion, it is important to keep it in full motion, and when it is stopped, it should be done gradually. This is accomplished by placing a vacuum chamber on the end of the suction pipe as shown in Fig. 4. The moving column of water compresses the air in the chamber at the

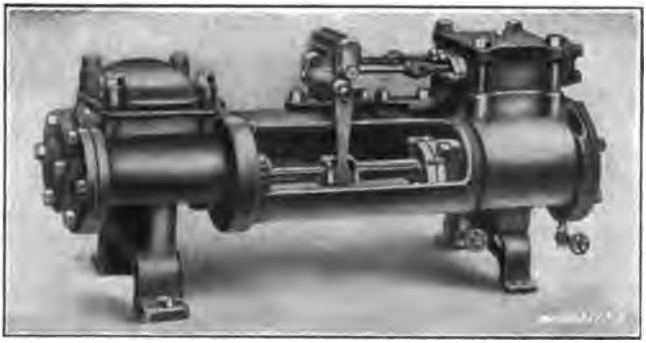

Fig. 5. Low-pressure Steam Pump

end of the stroke, and when the piston starts again, the air expands and thus aids in setting the column of water in motion once more. The vacuum chamber is usually made the same size as the suction pipe and of considerable length, rather than of large diameter and short.

Types of Pumps

Fig. 1 shows a duplex piston pump designed for water pressures up to 150 pounds. The two pumps are placed side by side, and so com-

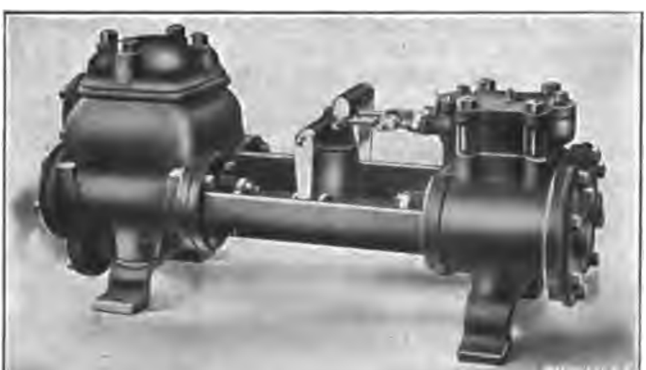

Fig. 6. Heavy Pattern Duplex Piston Pump

bined that one piston actuates the steam supply for the other, after which it finishes its own stroke and waits for its valve to be acted upon by the other pump before it can renew its motion. This pause allows the water valves to seat quietly, and prevents any harshness of

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motion. This particular pump is made in sizes from 2 x 1¼ x 2¾ inches up to 16 x 9¼ x 10 inches, in which the first dimension is the diameter of the steam cylinder, the second, the diameter of the water cylinder, and the third, the length of the stroke. The maximum capacity varies from 4.4 to 614 gallons per minute.

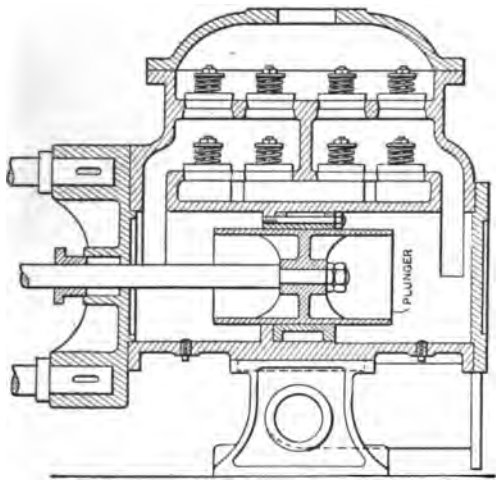

Fig. 7. Section of Plunger-type Pump

The pump shown in Fig. 5 is designed especially for use in apartment houses and private buildings, where low-pressure steam heating systems are in use, and where pumps are required to run with a low steam pressure. This condition requires a larger steam piston for a given size of water piston than is furnished in pumps of regular pat-

Fig. 8. Outside Packed Plunger Pump

tern. This pump is made in sizes ranging from 3 x ¾ x 3 inches to 9 x 3¼ x 10 inches with corresponding capacities of 1.5 to 70 gallons per minute.

Fig. 6 shows a heavy pattern duplex piston pump especially adapted to boiler feeding, although the larger sizes are used for fire purposes and general service work. The water ends are made to carry a work-

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ing pressure of 150 pounds, and the pumps are made in sizes ranging from 2 x 1¼ x 2¾ inches to 10 x 6 x 10 inches with corresponding capacities of 3 to 200 gallons per minute.

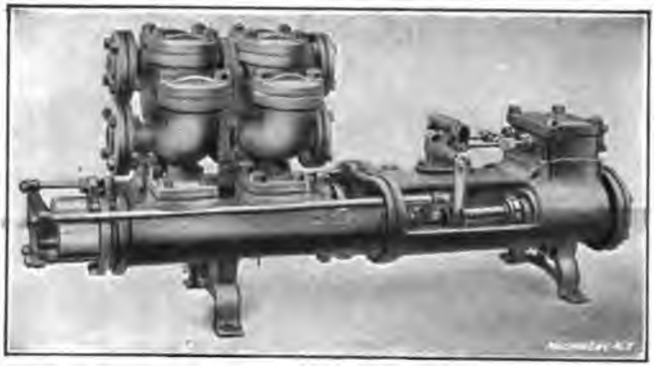

Fig. 9. Pot Valve Pressure Pump

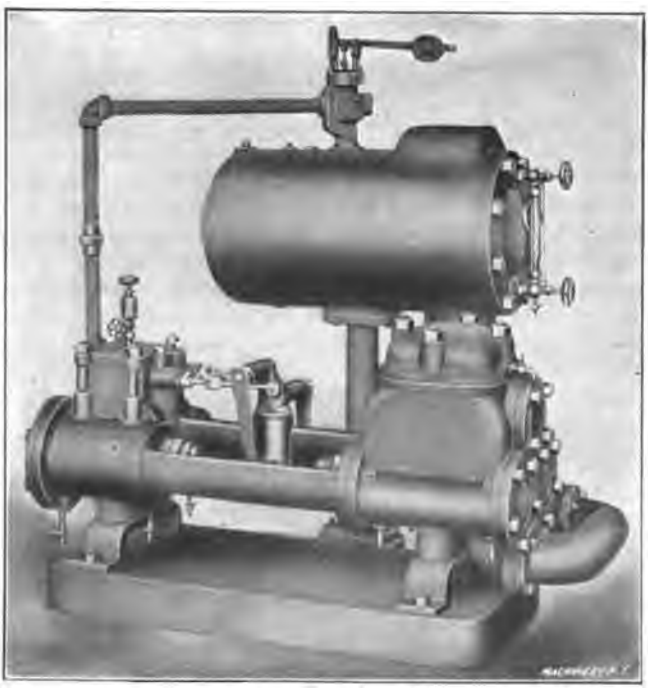

Fig. 10. Automatic Pump and Receiver

The pumps thus far described have been of the piston type shown in section in Fig. 2. A different design, known as a plunger pump, is illustrated in Fig. 7. In this case the piston is replaced by a plunger working in a renewable bushing, which is more easily replaced than a

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cylinder lining. For this reason plunger pumps are often preferred when the water is gritty, or when it for any other reason cuts out the packing rapidly.

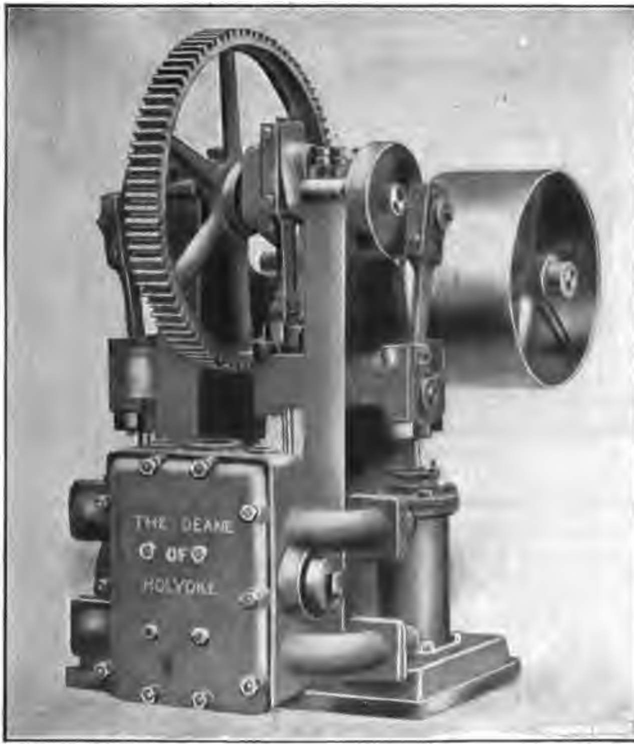

Fig. 11. Triplex Power Pump

The outside packed plunger pump, shown in Fig. 8, is designed especially for heavy service, and for use where the water carries large

TABLE III. CYLINDER DIAMETERS OF COMPOUND STEAM PUMPS

Diameter, High-pressure Cylinder, Inches	Diameter, Low-pressure Cylinder, Inches	Resulting Ratio of Expansion	Diameter, High-pressure Cylinder, Inches	Diameter. Low-pressure Cylinder, Inches	Resulting Ratio of Expansion
6	10	2 8	12	18	2.3
7	12	2.9	14	20	2.0
8	12	2.3	16	24	2.3
9	14	2.4	18	30	2.8
10	16	2.6	..	..	...

quantities of grit or other foreign matter of a similar nature. It is of heavy construction, being built for water pressures up to 250 pounds per square inch. One important feature of this design is the arrange-

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ment for packing the plungers from the outside, as the name implies. These pumps are especially adapted to boiler feeding, and are built in sizes ranging from 95 to 4500 boiler horsepower capacity.

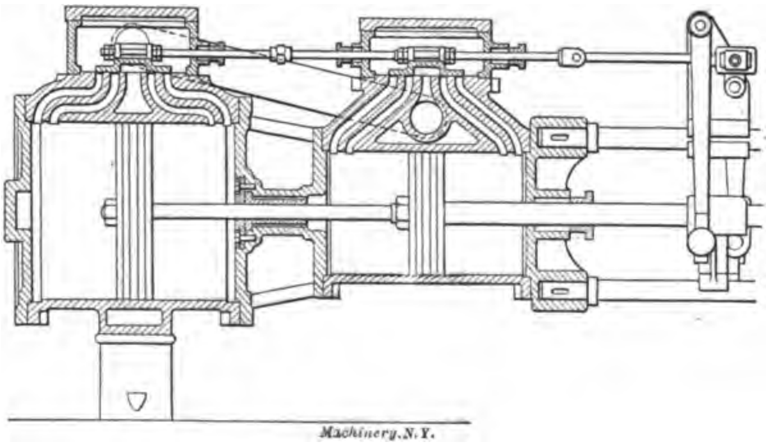

Fig. 12. Section of Compound Steam Pump

The pot valve pressure pump shown in Fig. 9 is extensively used for boiler feeding, it being designed for a working pressure of 300 pounds. It has four water cylinders and four single-acting plungers which are

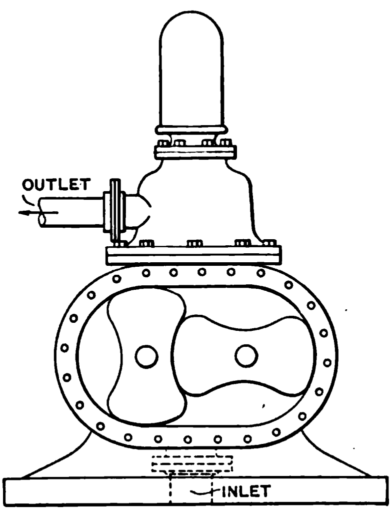

Fig. 13. General Construction of Rotary Pump

Fig. 14. Impeller of Centrifugal Pump

packed from the outside. The larger sizes are extensively used for elevators and hydraulic presses.

The outfit illustrated in Fig. 10 is used for automatically returning

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to the boilers the condensation from low-pressure heating systems, drying cylinders,, steam jackets, etc. A float within the receiver main-

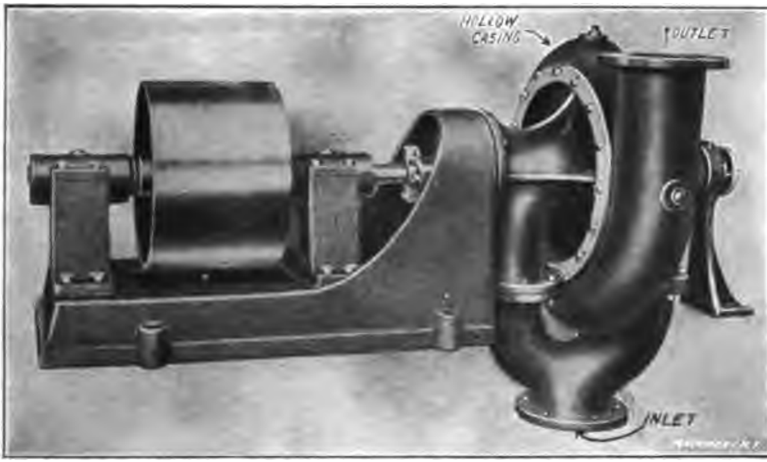

Fig. 15. Double Inlet Centrifugal Pump

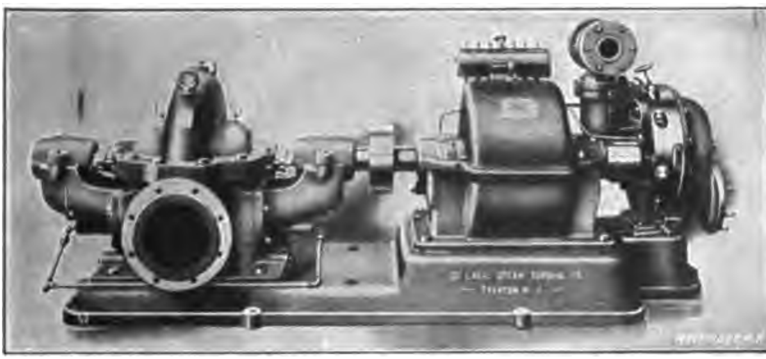

Fig. 16. Steam-turbine Driven Centrifugal Pump

tains a constant water level, starting and stopping the pump as required by means of lever connections between the float and a balanced valve in the steam supply pipe.

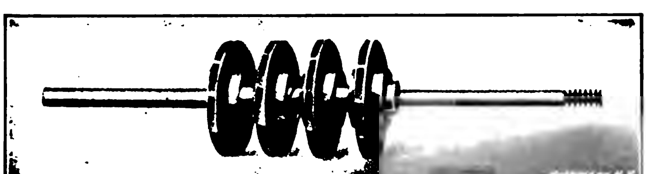

Fig. 17. Impellers of Turbine Pump

Triplex power pumps, (Fig. 11) are used in place of the direct-acting type where it is desired to operate them by belting from a line of

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shafting or from an engine shaft. Power pumps are not so well adapted to boiler feeding as steam pumps, because they run at a constant speed, and any variation in the amount of water required must be cared for by a relief valve in the discharge pipe, while the speed

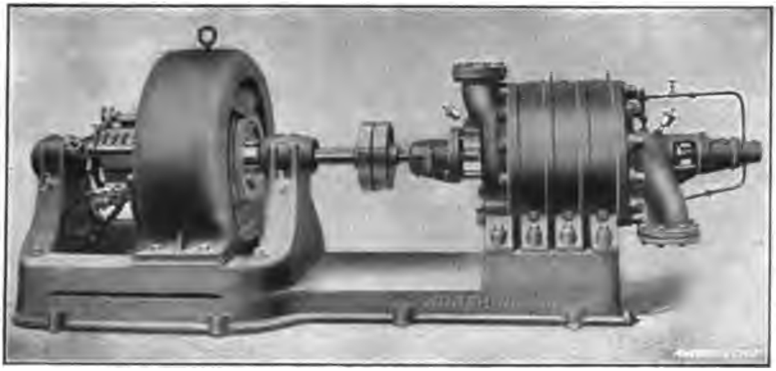

Fig. 18. Turbine Pump

of a direct-acting steam pump may be adjusted to meet varying requirements.

The ordinary form of direct-acting steam pump does not use steam like a steam engine, expansively, but takes it at boiler pressure for the full stroke. This makes it wasteful in the use of steam, so that with the larger sizes it is customary in many cases, where the steam pressure runs from 75 to 100 pounds, to use a compound pump. By doing this a saving of from 20 to 35 per cent is made with non-condensing pumps, and of from 25 to 40 per cent with condensing pumps. A common arrangement of the steam cylinders is shown in Fig. 12, the high-pressure cylinder, being at the right, and the low-pressure at the left. Steam is first admitted to the high-pressure cylinder, and from here it is exhausted into the steam chest of the low-pressure cylinder through a side pipe. The effect cf this is to use the steam expansively, the ratio of expansion commonly running from 2 to 4. Table III gives the sizes of cylinders commonly used for compound pumps and the resulting ratios of expansion.

Fig. 19. Diffusion Vanes of Turbine Pump

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Rotary Pumps

Pumps of the rotary type are employed for lifting and forcing water under low heads, and are somewhat more efficient than the direct-acting piston pump. Rotary pumps are driven by means of belts from line shafting, by gearing, and by direct-connected motors of various kinds. There are several designs of this type of pump in common use, one of which is shown in section in Fig. 13. This contains two *impellers*, each carried on a steel shaft running in bearings outside of the cylinder. These shafts are connected by gearing, and power is applied by means of belting to one of the shafts. The suction pipe is at the bottom, and the delivery at the top, the water being carried by the impellers which are always in contact as they revolve.

Centrifugal Pumps

Centrifugal pumps are used largely for circulating the water through condensers in turbine power plants, for forced hot-water circulation in certain forms of heating, and for many other purposes where large volumes of water are to be handled quickly. A common form of double-inlet centrifugal pump is shown in Fig. 15, and consists of a hollow casing inside of which is a revolving fan or impeller of the general form shown in Fig. 14. When in action, the water enters the opening at the center of the impeller, and is thrown outward into the casing, partly by the pressure of the blades, and partly by centrifugal force.

Pumps of this form are most efficient when working under pressure heads of from 20 to 30 feet, but may be so designed that lifts up to 500 feet or more may be obtained with a good degree of efficiency. The capacity of a centrifugal pump depends upon the size and speed of the impeller and height of lift. A centrifugal pump driven by a direct-connected steam turbine is shown in Fig. 16.

Turbine Pumps

A turbine pump is a centrifugal pump of slightly different design from the one just described. The turbine pump shown in Fig. 18 is driven by an electric motor, and contains four impellers mounted on a single shaft as shown in Fig. 17, these running between diffusion vanes of the form shown in Fig. 19. The principle of operation is practically the same as in the centrifugal pump already described. Turbine pumps are successfully employed for water works, elevator service, boiler feeding, hydraulic mining, fire service, etc.

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CHAPTER II

CONDENSERS

The purpose of attaching a condenser to a steam engine is to obtain a reduction in the back-pressure, due to the formation of a partial vacuum in the chamber into which the engine exhausts. The effect of a condenser is either to increase the power of an engine at a given steam consumption, or to reduce the steam consumption at a given power; this matter has been taken up in detail in MACHINERY's Reference Series No. 70, "Steam Engines."

There are four general types of apparatus commonly employed for condensing the exhaust steam and producing a vacuum in the engine

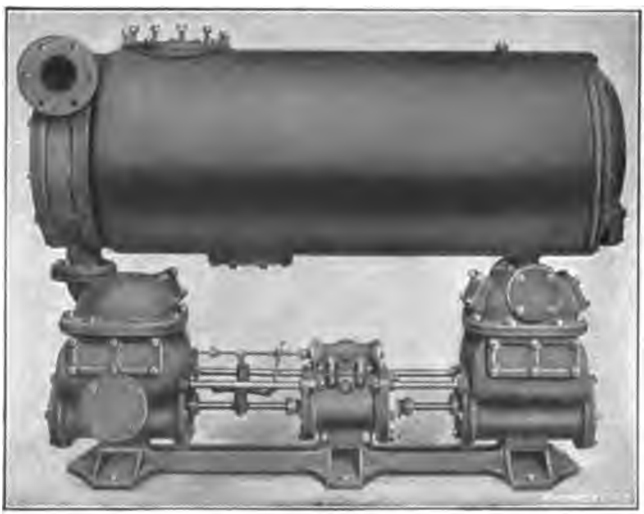

Fig. 20. Common Form of Surface Condenser

cylinder or exhaust pipe, known as *surface*, *jet*, *barometric* or *siphon*, and *atmospheric* condensers. These, in turn, each comprise two or three sub-divisions. For example, the surface condenser is made both vertical and horizontal in form; the jet condenser is made according to three different designs, the horizontal double-acting, the vertical single-acting, and the duplex; and the barometric condenser is made in two forms, the nozzle and the spray type.

Surface Condensers

A common form of surface condenser, together with its air and circulating pumps, is shown in elevation in Fig. 20, and in section in Fig. 21. The essential parts of this apparatus are a condensing cham-

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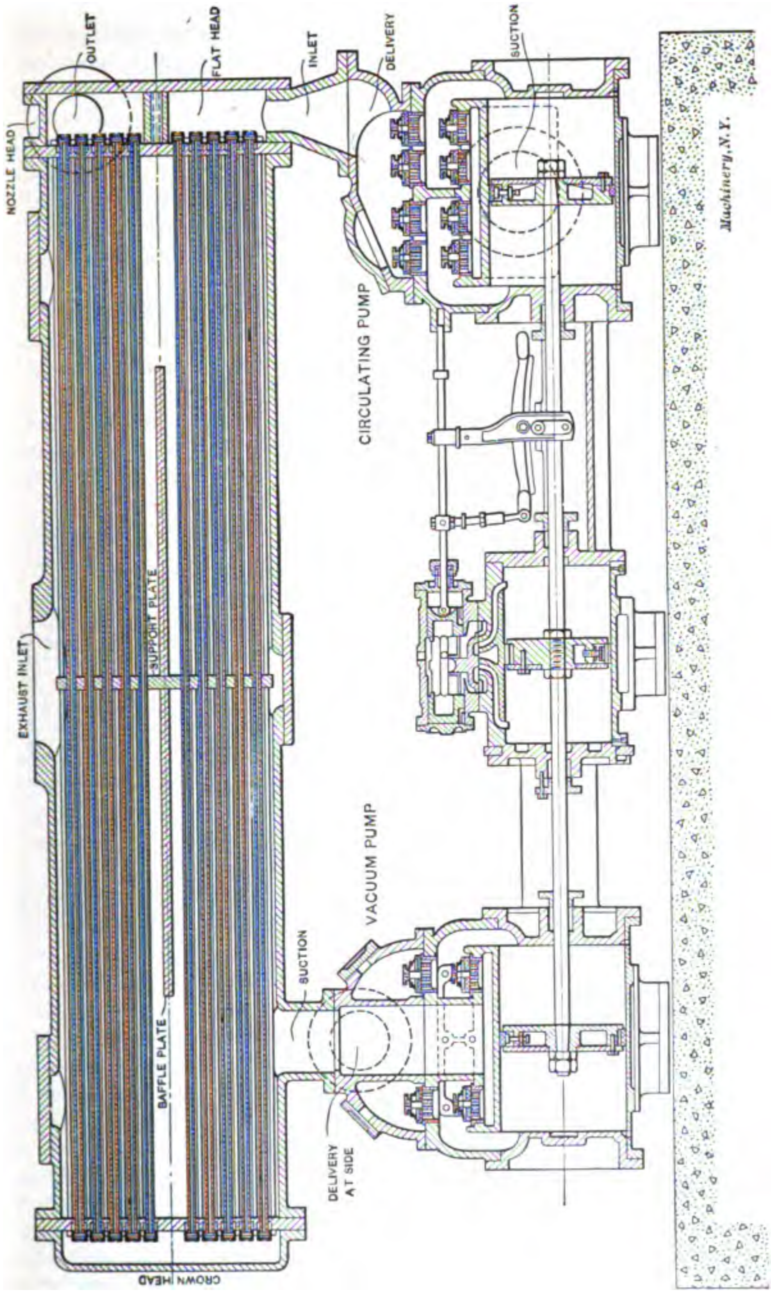

Fig. 21. Section of Surface Condenser

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ber, nearly filled with horizontal brass or copper tubes connecting with special chambers at each end, separated from the main body of the condenser by inner heads or tube sheets. Beneath the condensing chamber are the vacuum and circulating pumps, which in this case are driven by a single steam cylinder placed between them.

In action, the exhaust steam from the engine enters the shell at the top and fills the condensing chamber, flowing around and among the tubes, while the cooling water is made to pass through them by means of the circulating pump. The steam is condensed by contact with the cold surface of the tubes, and drops to the bottom of the shell where it flows to one end and enters the air or vacuum pump and is discharged into the hot-well. On entering the condensing chamber the steam strikes the baffle plate and is thrown in both directions towards the ends where it passes downward to the lower portion of the chamber, thus distributing itself over the entire tube surface. The cooling water is delivered from the circulating pump into the chamber directly above it, from which it passes through the lower group of tubes into the chamber at the left, and from here through the upper group of tubes to the outlet at the right.

The tubes are commonly made of drawn brass or copper, tinned on

TABLE IV. PITCH OF TUBES AND NUMBER OF TUBES PER SQUARE FOOT

Pitch of Tubes, Inches	Number per Square Foot of Space	Pitch of Tubes, Inches	Number per Square Foot of Space	Pitch of Tubes, Inches	Number per Square Foot of Space
1	172	$1\frac{5}{32}$	128	$1\frac{1}{4}$	110
$1\frac{1}{16}$	150	$1\frac{3}{16}$	121	$1\frac{9}{32}$	106
$1\frac{1}{8}$	137	$1\frac{7}{32}$	116	$1\frac{5}{16}$	99

both sides. The diameter usually varies from ½ to 1 inch, depending upon the length. The thickness of metal depends upon the diameter, averaging about 0.05 inch for a tube ¾ inch in diameter. The pitch of the tubes commonly varies from 1.5 to 1.7 of the diameter. This results in a certain number of tubes per square foot. (See Table IV.)

The condenser shown in Fig. 21 is known as the single-tube type, and is one of the simplest arrangements. The tubes are connected to the heads in various ways. In some cases they are fastened rigidly at one end and allowed to move at the other, in order to take care of the expansion and contraction. Tubes of this kind are made steam- and water-tight by the use of a stuffing box and gland. In other makes this arrangement is provided at both ends, as shown in Fig. 22.

Another tube construction is shown in diagrammatical form in Fig. 23, and is known as the double-tube pattern. In this design the water enters and leaves the condenser at the same end, as in Fig. 21, first passing through the inner tube and then to the outlet by way of the outer tube, as indicated by the arrows. Since but one end of the tube is fixed, the opposite end merely projecting into the steam or

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condensing space, it is free to expand and contract independently of the shell and of the other tubes. In other arrangements both ends of the tubes are expanded rigidly into tube sheets or inner heads, and the expansion it taken care of by a special construction of the shell.

The cooling surface depends upon the temperature and weight of the steam to be condensed, and the initial and final temperatures of the

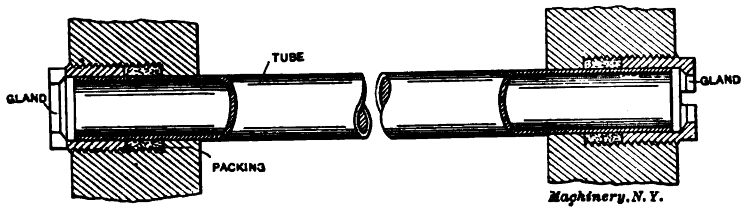

Fig. 22. Condenser Tube with Stuffing Box and Gland at both Ends

cooling water. The formula commonly used for determining the tube or cooling surface in any given case is:

$$S = \frac{W L}{180 (T - t)} \qquad (10)$$

in which

S = cooling surface in square feet,
W = weight of steam to be condensed per hour, in pounds,
T = temperature of the steam at condenser pressure, in degrees F.,
t = average temperature of the circulating or cooling water, in degrees F.,
L = latent heat of steam at temperature T.

The condenser shell is made of cast iron, either circular or rectangular in section, that shown in Figs. 20 and 21 being of the former design. It is sometimes mounted on separate supports, but more com-

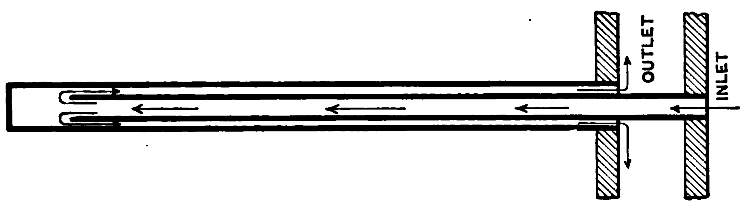

Fig. 23. Condenser Tube of the Double-tube Pattern

monly combined with the vacuum and circulating pumps as shown. It is customary to carry the tubes quite close to the shell, as it is found by experience that the steam will readily spread to all parts of the condensing chamber. Hence, the tube spacing arrangement becomes entirely a matter of mechanical construction. After computing the cooling surface required, the diameter of the tube may be assumed, the length not exceeding about 120 diameters, and the spacing may be taken from Table IV. This practically determines the size of the shell.

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For marine work, surface condensers are used almost exclusively, and they are also employed in stationary power plants. They are more bulky for a given capacity than other types, but may be used with any kind of cooling water, which is a decided advantage if the condensed steam is to be fed into the boilers again. This is often of much importance, where the feed water supply is of poor quality, and can be done without injury if the oil is thoroughly removed from the

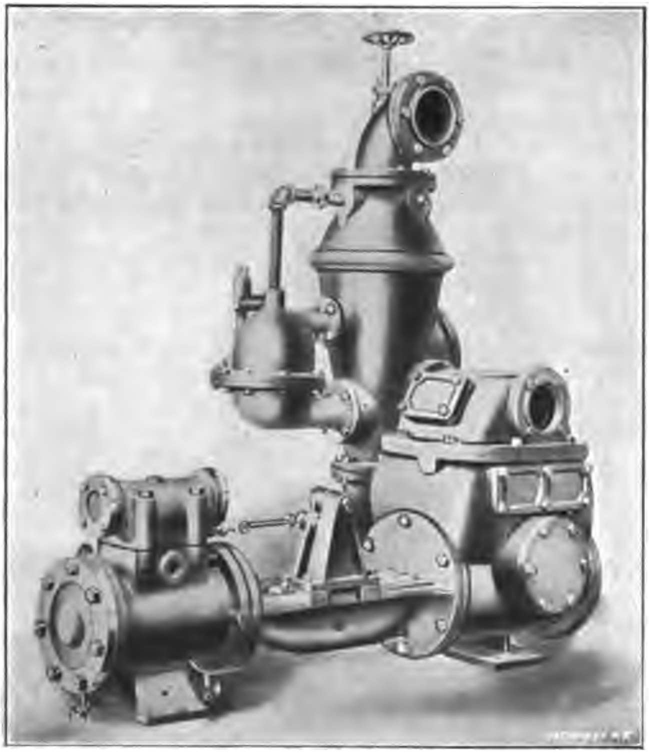

Fig. 24. External View of Jet Condenser

exhaust steam. In such a case only from 10 to 12 per cent of the boiler supply is made up of fresh water.

Jet Condensers

In a jet condenser the steam and condensing water mingle in the condensing cone, and the condensed steam is discharged with the water. As the condensing water acts directly upon the steam by actual contact, it will produce a greater drop in pressure for a given amount of water than when used in a surface condenser. When the condensed steam is fed back into the boilers it is evident that a portion of the cooling water goes with it; hence, in this case, the supply must be of a quality which is not detrimental to the boiler plates.

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An external view of a jet condenser is shown in Fig. 24, and a section through the condensing cone in Fig. 25. By referring to the latter illustration, it is seen that the exhaust steam enters at the top of the condenser and then meets the injection or cooling water, which is drawn in by suction due to the partial vacuum and discharged in the form of a spray by means of the adjustable cone shown at the center. The result is an instantaneous and complete condensation of the steam, which mixes with the cooling water, and with it is drawn into the pump and discharged either to the sewer or hot-well as the case may be.

The vacuum breaker shown at the right prevents the water from rising any higher in the condenser than to its proper level. If by accident the air pump should stop, the water will rise in the condenser sufficiently to lift the float, thus admitting air and breaking the vacuum. As soon as the pump is again started, the float drops to its normal position, the air relief valve closes, and the work of condensation is again resumed.

Before determining the size of pump for a condenser, the volume of cooling water must be computed.

This may be found with sufficient exactness for a jet condenser by the formula:

$$Q = \frac{S - (D - 32)}{D - I} \qquad (11)$$

in which

Q = weight of cooling water per pound of steam condensed,

S = total heat in one pound of steam above 32 degrees, at terminal pressure,

I = initial temperature of cooling water,

D = final temperature of cooling water.

The terminal steam pressure will vary with the type of engine, the initial pressure, and the ratio of expansion. For average conditions, when no exact data is at hand, it may be assumed as 20 pounds per square inch, absolute. The total heat of evaporation corresponding to this pressure is 1151 heat units, which may be taken as the value of S in the formula. The initial temperature of the cooling water is commonly taken as 70 degrees F. in the summer time, and the final temperature as 110 degrees F.

When the condensing water is taken from ponds and streams, its temperature will be only slightly above the freezing point in the winter, so the quantity required will be considerably less than in the summer. When making an estimate for the entire year, it is customary to assume an average temperature of 50 degrees F.

When designing the pumps for a condenser it is necessary to make them of sufficient size to handle the maximum volume of condensing water, which of course increases with the initial temperature of the cooling water. In the case of surface condensers, the weight of water computed by Formula (11) should be increased about 20 per cent.

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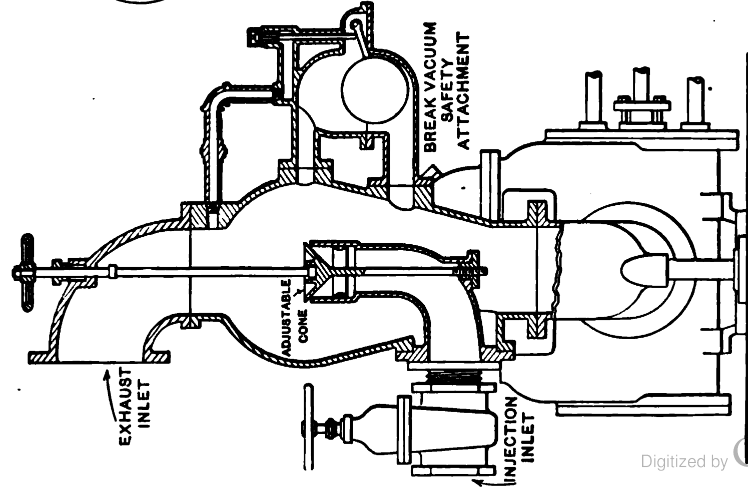

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Fig. 25. Section through Jet Condenser

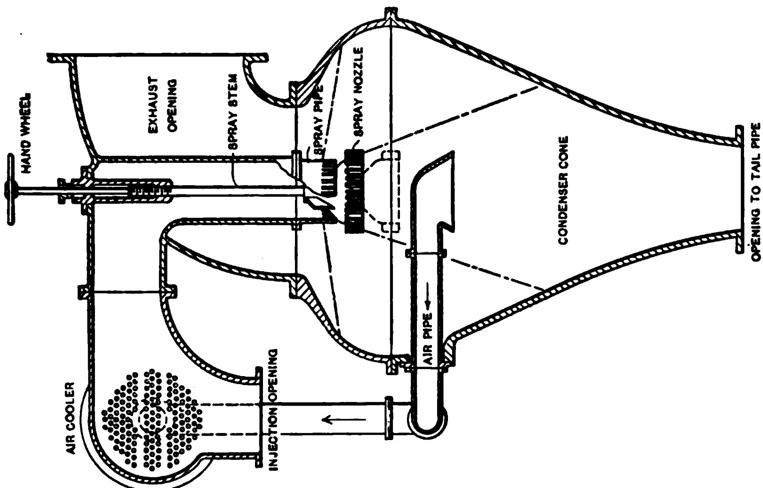

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Fig. 26. Condenser Head of the Spray Type

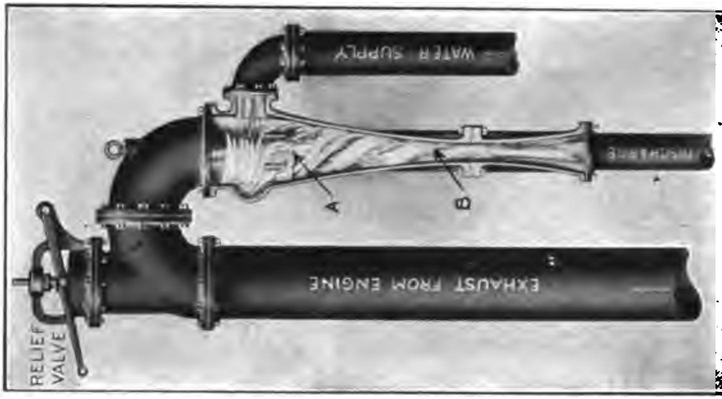

Fig. 27. Siphon Condenser of the Nozzle Type

Barometric or Siphon Condensers

The barometric or siphon condenser is particularly well adapted to plants in which the condensing water is suitable for boiler feeding, and also to any plant where condensation of steam only is desired, the condensing water not being used. These condensers are able to maintain a vacuum of 26 to 27 inches without the use of pumps or valves, and require practically no adjustment.

A siphon condenser of the nozzle type is shown in Fig. 27. This type consists of a steam chamber in the form of a return bend, and is fitted with a relief valve at the top which closes automatically, due to its own weight assisted by a light spring. The steam flows through the regulating nozzle *A*, while the cooling water enters at the side of the nozzle chamber, and flows in a thin sheet or film through the annular orifice formed between the nozzle and the chamber wall. The throat or combining tube *B* is just below the nozzle *A*, and is of the tapering form shown. This connects with the discharge or tail pipe and should be at an elevation of 34 feet above the surface of the hot-well. In operation, the condensing water passing through the annular orifice formed by the nozzle *A* flows downward in a cone-shaped film into the combining tube *B*, where its velocity is sufficiently increased to enable it to carry air along with it, thus producing a vacuum in the steam exhaust pipe. The steam flows downward through the regulating nozzle and into the cone-shaped film of water, where it is condensed.

A condenser head of the spray type is shown in Fig. 26. This is used in connection with water and vacuum pumps as indicated in Fig. 28. The condenser is placed about 30 feet above the hot-well, and the water falls out of it by gravity against the pressure of the atmosphere. The sectional view of the condenser cone and air cooler shows the method of distributing the condensing water within the chamber. This is done by means of a series of teeth at the lower end of the spray pipe in connection with a similar series upon the nozzle just below it. The falling water in the cone entraps a portion of the air set free by the condensation of the steam, and carries it down into the tail pipe, so that a partial vacuum is formed in the condenser and exhaust piping.

In order to obtain the highest range of vacuum without using an abnormal amount of water to carry off the air, a separate dry vacuum pump is used, by means of which the air not carried off by the water is taken from the empty space under the spray cone in the condenser. On its way to the vacuum pump, the air passes through a cooler, consisting of a large number of tubes through which the condensing water passes, and around which the air circulates on its way to the pump. The usual sizes for the exhaust pipe and connection for the condenser head for different capacities are given in Table V.

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Atmospheric Condensers

A vertical section through one form of atmospheric condenser is shown diagrammatically in Fig. 29. This condenser consists of an outer shell, cylindrical in form, to which are attached upper and lower tube sheets *A* and *B*, as shown. The shell is filled with air-tubes of 4-inch wrought-iron pipe, extending about 4 inches above the upper tube-

TABLE V. EXHAUST PIPE DIMENSIONS FOR SPRAY TYPE CONDENSERS

Weight of Steam to be Condensed per Hour, Pounds	Diameter of Exhaust Pipe and Condenser Connection, Inches	Weight of Steam to be Condensed per Hour, Pounds	Diameter of Exhaust Pipe and Condenser Connection, Inches	Weight of Steam to be Condensed per Hour, Pounds	Diameter of Exhaust Pipe and Condenser Connection, Inches
2,000	5	5,000	9	10,000	12
3,000	7	6,000	9	15,000	14
4,000	8	8,000	10	20,000	14

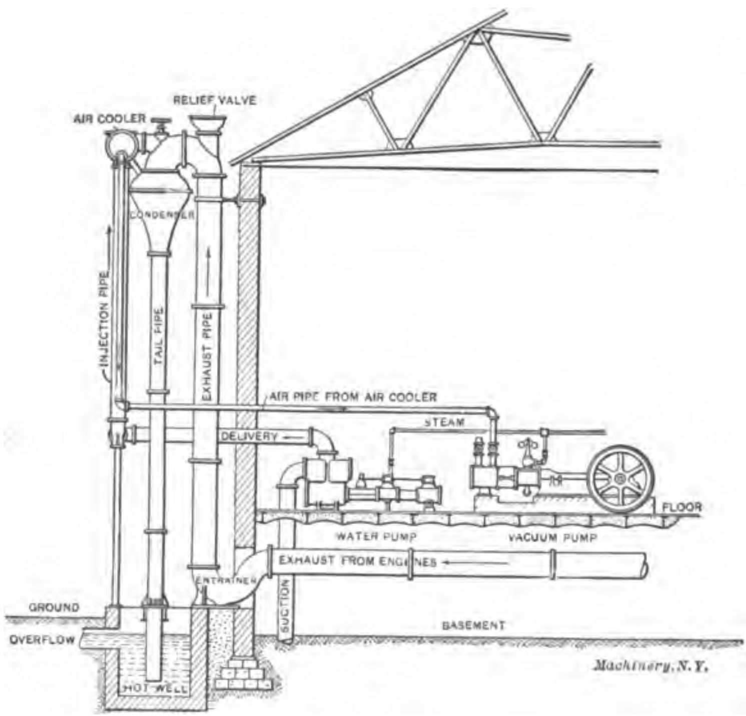

Fig. 28. Arrangement of Condenser shown in Fig. 26

sheet. The exhaust steam enters through a special form of distributor near the bottom of the shell, and is made to circulate among the tubes by means of baffle plates not shown.

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The cooling effect is produced by an upward movement of air through the tubes, which is greatly increased by pumping water into the water-pan above the upper tube sheet and allowing it to trickle downward through the tubes into the cistern below. The upper ends of the tubes are notched so that the water in passing into them spreads into a thin sheet, covering the inside surface. The exhaust steam in the shell heats the tubes and the film of water, causing the latter to evaporate rapidly, thus saturating the air and causing it to pass swiftly up the tube, carrying with it large quantities of heat taken from

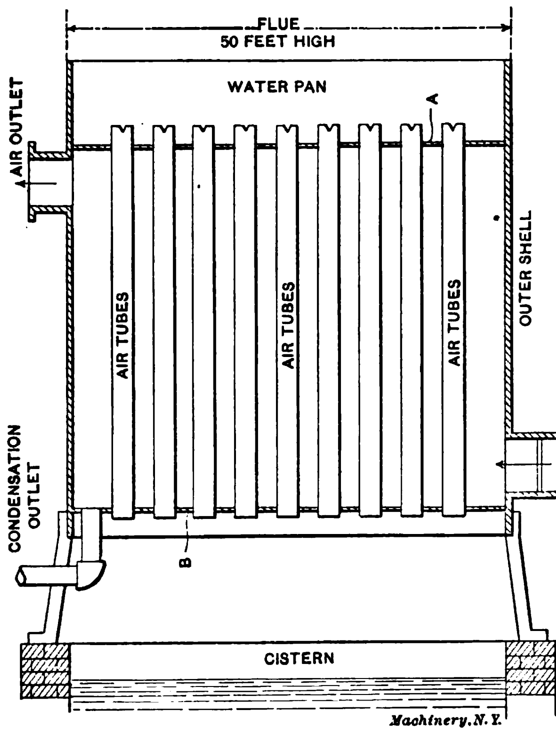

Fig. 29. Section through Atmospheric Condenser

the condensing steam. The water of condensation is taken off through a drain connection in the lower tube sheet, and the air from the upper outlet, as indicated. These pipes are connected and carried to a vacuum pump not shown in the illustration. The velocity of air-flow through the tubes is increased by carrying up a flue of light steel to a height of about 50 feet above the condenser.

Cooling Towers

From 20 to 30 per cent may be saved in fuel by the use of a condenser. This estimate is based on the assumption that the water used for condensing the steam can be obtained free of cost. When the plant

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is located in a city where the water must be obtained at regular city rates, it often happens that it is more economical to run non-condensing than to purchase cooling water. In order to do away with the water expense, so-called cooling towers are now extensively used. By means of these the condensing water may be cooled and used over and over again with a comparatively small loss by evaporation.

There are various forms of cooling towers in use. The general principles, which are practically the same in each case, are well illustrated in Fig. 30. The tower consists of a steel shell inside of which are suspended a number of mats of a special steel wire cloth, galvanized after weaving. The mats are, in effect, a metallic sponge, capable of holding a large quantity of water in suspension, which accumulates and drips off into the reservoir at the bottom. The water to be cooled is pumped to the top of the tower and discharged through a number of distributing nozzles upon the tops of the mats. From here it drips to the bottom, exposing a large surface to the air which is forced upward by the fans placed at the bottom of the tower.

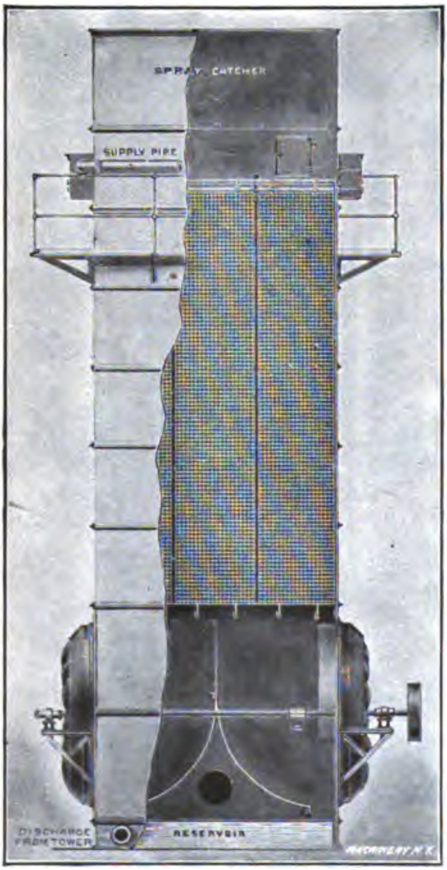

Fig. 30. Cooling Tower

The cooling effect is due to three causes: first, radiation from the sides of the tower; second, the contact of the water with the cooler air; and third, the most important of all, the heat carried away in the process of evaporation. The proportion due to the latter cause may be easily calculated as follows: The latent heat of evaporation at 110 degrees is 1035; that is, 1035 heat units are absorbed in changing 1 pound of water from a temperature of 110 degrees into vapor at the same temperature. Suppose it is desired to cool 100 pounds of water 40 degrees. This will evidently require the removal of $40 \times 100 = 4000$ heat units. If the evaporation of 1 pound of water will absorb

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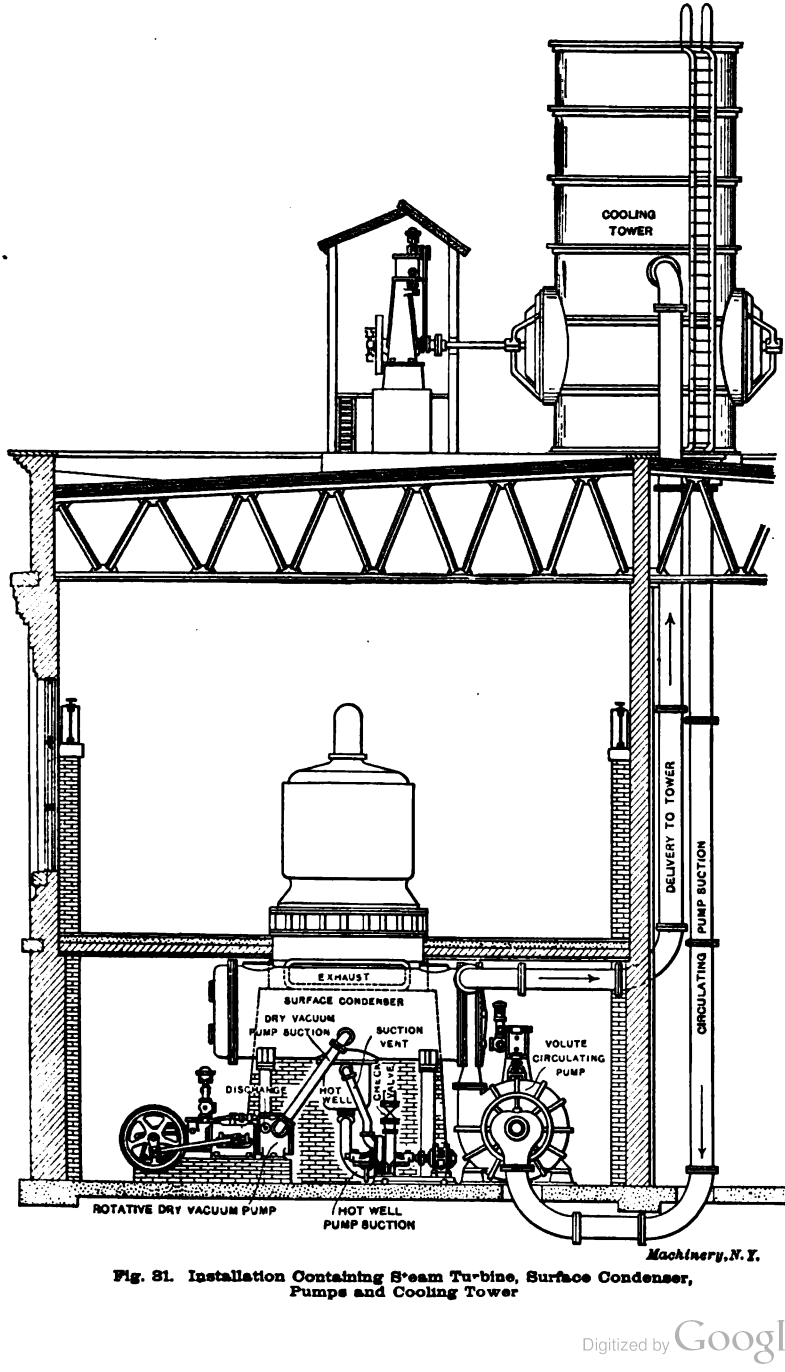

Fig. 31. Installation Containing Steam Turbine, Surface Condenser, Pumps and Cooling Tower

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1035 heat units, then 4000 ÷ 1035 = 3.86 pounds is the amount of evaporation required to remove 4000 heat units, and therefore represents the loss necessary to cool 100 pounds of water 40 degrees in this manner; that is, 3.86 pounds of water will be evaporated for every 100 pounds cooled 40 degrees in passing through the tower. With the best forms of cooling towers the temperature of the condensing water may easily be reduced from 40 to 50 degrees with a loss from evaporation not exceeding 3 to 4 per cent.

The volume of air to be passed through a cooling tower will depend upon the temperature and relative humidity, the condenser pressure, the weight of condensing water, and its final temperature. Professor E. F. Miller gives the results of two tests which are tabulated below,

TABLE VI. VOLUME OF AIR REQUIRED FOR COOLING TOWERS

Relative Humidity of Air	Cubic Feet of Air required per Pound of Exhaust Steam	Relative Humidity of Air	Cubic Feet of Air required per Pound of Exhaust Steam
0.60	410	0.80	455
0.70	420	0.90	480

and which will be found useful in estimating the air volume for average conditions. The first case (Table VI) relates to a condenser maintaining 28 inches of vacuum, and using 40 pounds of condensing water per pound of exhaust. The final temperature of the water is assumed to be 95 degrees, and the air temperature 70 degrees.

The second case (Table VII) relates to a condenser maintaining 26 inches of vacuum, and using 20.7 pounds of condensing water per pound of exhaust. A final water temperature of 119 degrees, and an air temperature of 70 degrees, is assumed.

TABLE VII. VOLUME OF AIR REQUIRED FOR COOLING TOWERS

Relative Humidity of Air	Cubic Feet of Air required per Pound of Exhaust Steam	Relative Humidity of Air	Cubic Feet of Air required per Pound of Exhaust Steam
0.60	176	0.80	184
0.70	180	0.90	188

An installation containing a steam turbine, surface condenser, pumps, and cooling tower, is shown in Fig. 31. The supply of cold water for the condenser is drawn from the bottom of the cooling tower by a centrifugal pump, and then forced through the condenser, from the top of which it again passes to the tower to be cooled. In the towers shown, the air has been forced through them by fans. Towers are also made for natural draft, in which case the flue is extended to a considerable height above the cooling surfaces.

A surface condenser requires two pumps, one called the circulating pump, for forcing the condensing or cooling water through the tubes,

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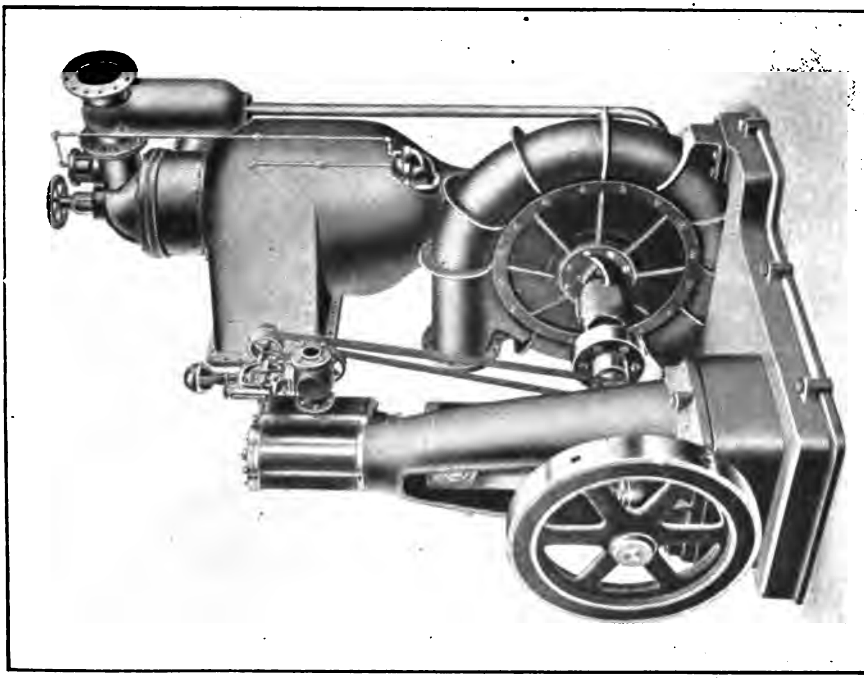

Fig. 33. Condenser with Centrifugal Pump

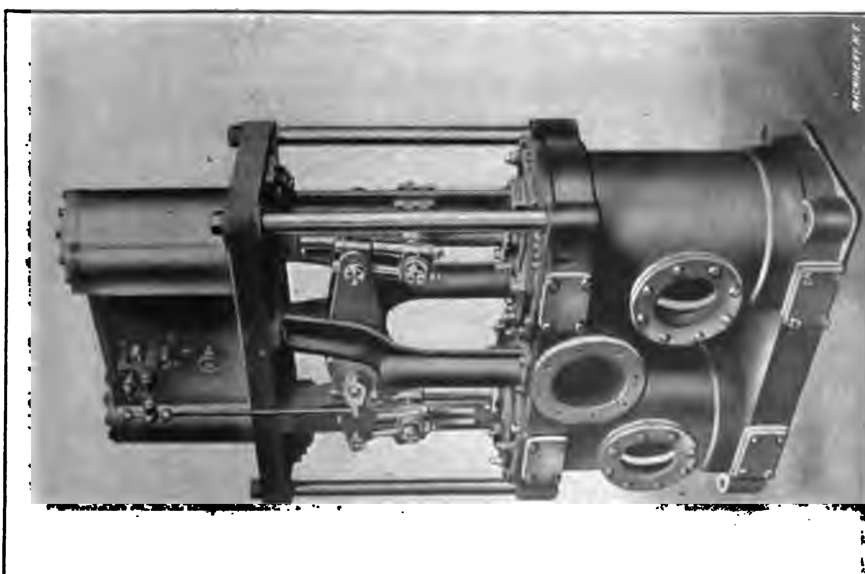

Fig. 32. Direct-acting Twin Vacuum Pump

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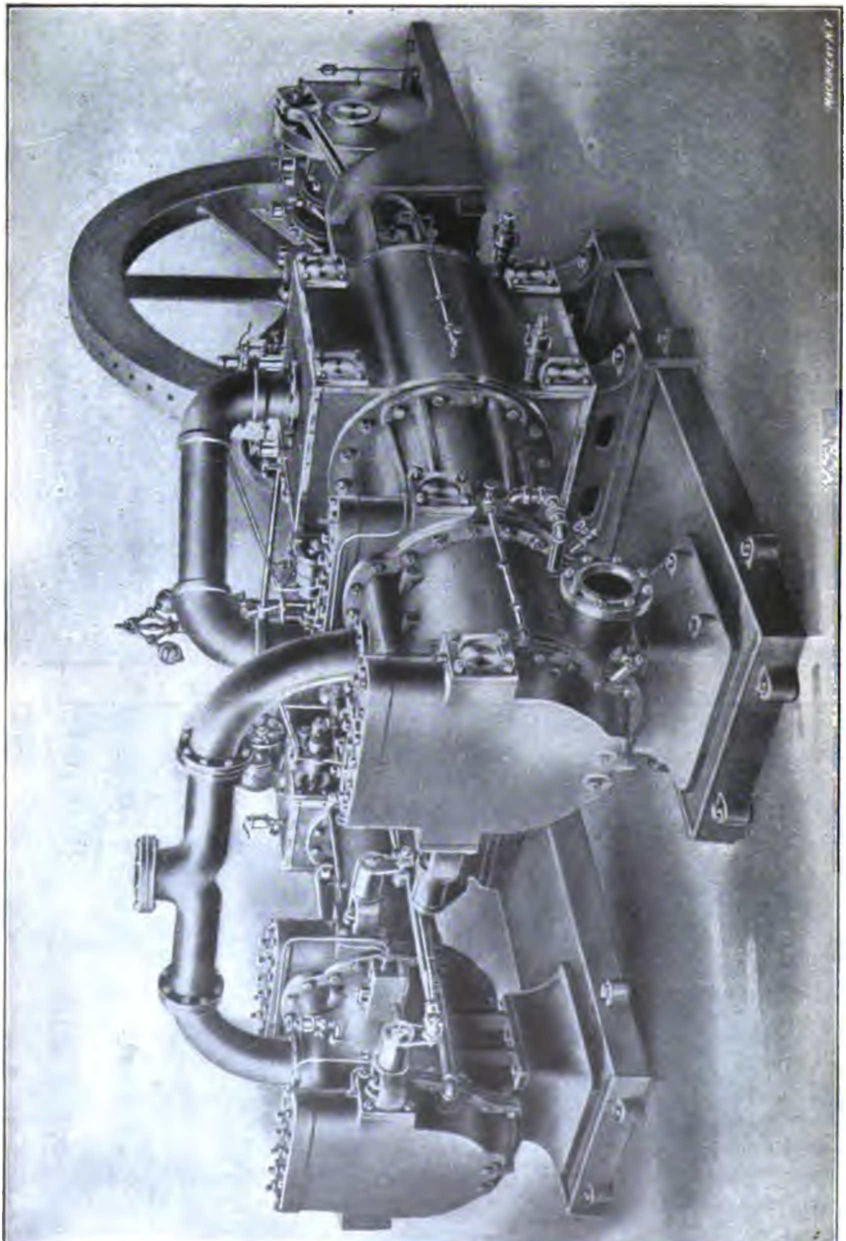

Fig. 34. Large Duplex Pump for Power Plant Service

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and one called a vacuum or air pump for withdrawing the condensed steam and the air which it may contain. Separate pumps may be used for this purpose or the two may be combined with a single steam cylinder as shown in Fig. 21. Both direct-acting steam pumps and those of the centrifugal type are used for circulating pumps, while the direct-acting pump only, either of the vertical or horizontal type, is commonly employed for removing the air and condensation.

A direct-acting vertical twin vacuum pump, of the single-acting type, is shown in Fig. 32. This type of pump is used in connection with both

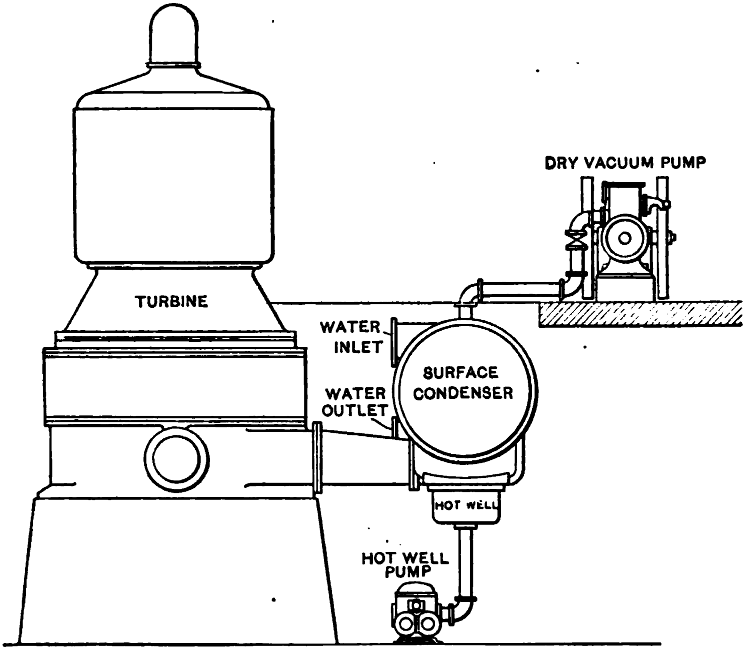

Fig. 35. Diagrammatical View of Steam Turbine with Surface Condenser

surface and jet condensers, and has the advantage of occupying a comparatively small floor space.

Jet condensers, as commonly used, require simply a vacuum pump, the cooling water being drawn into the condenser head by suction. Both direct-acting steam pumps and centrifugal pumps are used for this purpose. Fig. 24 shows an outfit equipped with a direct-acting horizontal pump, while in Fig. 33 the condenser is provided with a centrifugal pump driven by a direct-connected steam engine. In some cases a pump is also used for forcing the water into a jet condenser instead of drawing it in by suction.

The high vacuum necessary to obtain the best efficiency from a steam turbine has brought into use the dry vacuum pump. With this arrangement the air and condensed steam are removed from the condenser by

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means of separate pumps. Dry vacuum pumps are usually of the rotative type, and require a higher grade of workmanship than is necessary with pumps used for a moderate vacuum. A large duplex pump of this type, designed especially for power plant service, is shown in Fig. 34. The air cylinders are at the left, and the steam cylinders between them and the main shaft.

A steam turbine arranged for high vacuum, and employing a surface condenser, is shown in Fig. 35. The dry vacuum pump is shown at the right, and is so connected that it removes the air from the top of the condenser. The condensed steam falls into the hot-well beneath

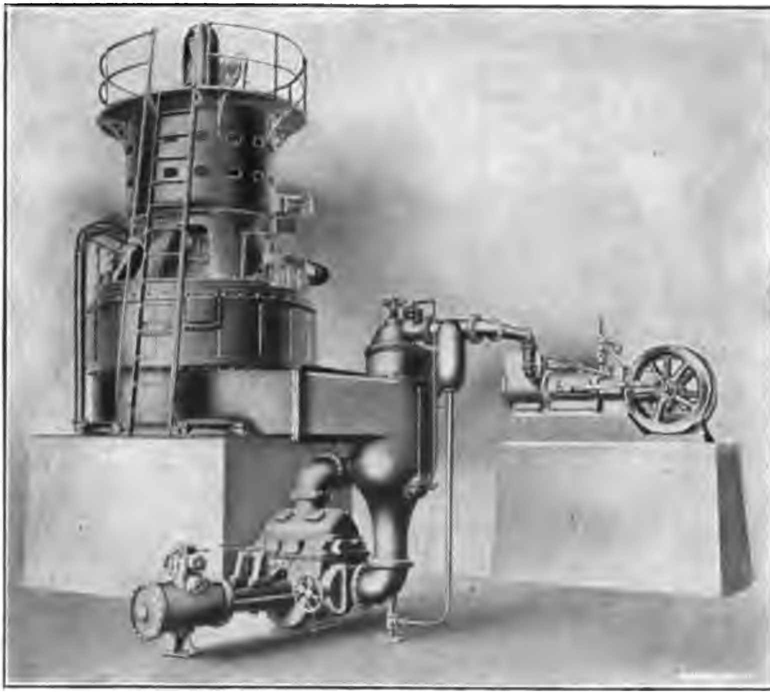

Fig. 36. Steam Turbine Installation with Jet Condenser

the condenser, and is removed by the hot-well pump. A similar arrangement for a jet condenser is shown in Fig. 36.

The circulating pump should be proportioned to handle the required volume of cooling water the same as for tank service, and in the manner already described. A common method of determining the size of the air cylinder is by use of the following equation:

$$V = W \times C \qquad (12)$$

V = piston displacement, in gallons per minute,
W = weight of steam condensed, in pounds per hour,
C = 0.045 for double-acting horizontal pumps; 0.022 for single-acting vertical pumps.

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CHAPTER III

STEAM AND WATER PIPING

Some of the more important points to be kept in mind when designing a system of piping for a power plant are as follows:

1. The route between the boilers and engines should be made as direct as practicable under existing conditions.
2. Provision should be made for expansion and contraction, so that excessive strains will not be thrown upon the pipe and fittings.
3. The piping should be so supported and anchored that vibration will be eliminated, so far as possible.
4. All supply piping should be of such size as to avoid undue losses in pressure and excessive velocities. Low velocities should be the rule in exhaust lines, in order to minimize the back-pressure upon the engines.
5. Proper joints and packing should be used to make the system steam- and water-tight, and all pipes and fittings should be thoroughly insulated to prevent excessive loss of heat from radiation.
6. Special attention should be given to the matter of drainage; the condensation from separators, main headers, and all other low points in the system should be thoroughly removed and returned to the boilers.
7. Separate headers should be provided for the engines and auxiliaries, and the whole system should be divided into sections, or else duplicated so far as practicable.

Piping Materials

Under the heading of piping materials are included the different kinds of pipe used in power plant construction, fittings, valves, etc. Although designated as wrought-iron pipe, the pipe commonly used in power plant work is made of wrought steel. When of good quality as to malleability and ductility, with joints properly welded, there is no advantage in using the more expensive wrought-iron pipe.

Pipe is classed according to weight or thickness of shell, being known as standard, extra strong, and double extra strong. Taking the weight or thickness of standard pipe as 1, the thickness of extra strong pipe is 1.4, and of the double extra strong, 2.8. All of these weights of pipe have the same outside diameter, the additional thickness of metal being added to the inside of the pipe. The standard pipe of commerce, commonly known as "Merchant" pipe, is lighter than the standard or "full weight" pipe. Manufacturers usually specify that the latter may vary 5 per cent from the standard, but as a matter of fact, it almost invariably falls below.

Pipe 3 inches in diameter and smaller is commonly butt welded, and

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larger sizes lap welded. While it is possible to make larger pipe by the former process, the cost is greater, and it has, therefore, become the practice of manufacturers to limit the diameter of butt welded pipe to 3 inches.

Standard weight pipe is used for exhaust lines and for pressures up to 125 pounds, although some engineers consider it safe for pressures of 200 pounds or more. Heavier weights, however, are generally used for higher pressures, and also for pipes which, due to their location, are especially subject to corrosion. Table VIII gives data and dimensions relating to standard weight pipe.

TABLE VIII. STANDARD PIPE DIMENSIONS

Diameter			Thickness of Wall, Inches	Internal Area, Square Inches	Exposed Surface per Foot, Square Feet	Weight per Foot, Pounds	Number of Threads per Inch
Nominal, Inches	External, Inches	Actual Internal, Inches					
1	1.31	1.05	.13	.86	.345	1.67	11½
1¼	1.66	1.38	.14	1.50	.434	2.24	11½
1½	1.90	1.61	.14	2.04	.497	2.68	11½
2	2.37	2.07	.15	3.36	.621	3.61	11½
2½	2.87	2.47	.20	4.78	.752	5.74	8
3	3.50	3.07	.22	7.39	.916	7.54	8
3½	4.00	3.55	.23	9.89	1.047	9.00	8
4	4.50	4.03	.24	12.73	1.178	10.26	8
5	5.56	5.04	.26	19.99	1.456	14.50	8
6	6.62	6.06	.28	28.89	1.734	18.76	8
7	7.62	7.02	.30	38.74	1.988	23.27	8
8	8.62	7.98	.32	50.04	2.258	28.18	8
9	9.62	8.94	.34	62.73	2.520	33.70	8
10	10.75	10.02	.37	78.84	2.814	40.00	8
11	11.75	11.00	.37	95.03	3.075	45.00	8
12	12.75	12.00	.37	113.10	3.337	49.00	8

Spiral riveted pipe is a pipe frequently used for low-pressure piping of large size, as in heating work, and for exhaust lines. Its advantages over wrought-iron pipe are its lightness and lower cost. Pipes which are to carry hot water should be of brass, owing to the corrosion of wrought-iron or steel when used for this purpose. Pipes of this class include the connections between boilers and feed pumps, the attachment of boiler accessories, and all connections around hot-water boilers for lavatory purposes. Seamless drawn brass tubing is made in sizes to correspond with standard wrought-iron pipe.

The fittings used for making up wrought-iron pipe are usually of cast iron, although wrought-iron flanges are used to some extent in the best class of high-pressure work. For the smaller sizes of piping up to 2 or 2½ inches screwed fittings are commonly used, an elbow of this pattern being shown in Fig. 37. In the case of larger pipes, the flange

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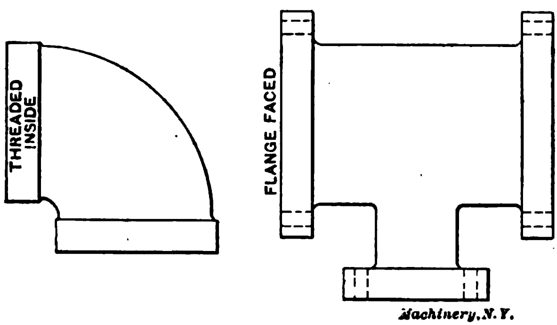
fitting is almost universally employed, it being much easier to connect where the space is limited, and also easier to take down in case of repairs. A flanged tee is shown in Fig. 38. Cast-iron fittings are made in a great variety of forms to meet almost any requirements which may occur in the design of a system of piping. They are made regularly in two weights: standard, for pressures up to 125 pounds per square inch, and extra heavy, for higher pressures up to 250 pounds.

Gate valves are generally used in power plant work except where an angle valve will answer the purpose and take the place of a fitting. They offer but little resistance to the passage of steam through them, and if placed with the spindle in a horizontal position, or vertical with the hand-wheel at the top, they cannot form pockets in the piping for the accumulation of condensation. For all important lines of piping, the rising spindle valve, shown in Fig. 39 should always be used, so that the engineer can tell at a glance whether it is open or closed.

Valves 6 inches and larger in size are usually provided with a by-



Figs. 37 and 38. Pipe Fittings

pass as shown in Fig. 40. This allows the steam to be admitted slowly when first turning it on, and also equalizes the pressure on both sides of the main valve so that it can be opened easily, without scoring the faces of the gate and seat. Globe valves may be used in small vertical pipes, drip lines, etc.; when placed in horizontal pipes, care should be taken to have the stem horizontal. Check valves for vertical feed pipes should be of the "spring" type. Swing checks are commonly used in horizontal pipes, but sometimes give trouble by chattering or beating at each stroke of the feed pump.

The matter of pipe joints is an important one in the design and construction of a power plant. One of the simplest joints is that shown in Fig. 41. In this case the pipes are threaded with a full taper and screwed into the flanges by power, so that the ends project slightly, and are then faced off in a lathe, a thin cut being taken from the whole face of the flange. The joints are commonly packed with a corrugated copper gasket placed inside the bolt circle. This form of gasket is very durable, often lasting as long as the pipe. Piping made up with flanges of this kind is easily disconnected for repairs, as a sec-

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tion may be removed without springing the joint apart, which is a matter of much importance in the case of long mains of large size.

Another type of joint often used is shown in Fig. 42. Here the pipes are threaded and screwed into the flanges as before, but instead of being plane surfaces, the flanges are tongued and grooved as indicated, with a copper gasket placed at the bottom of the groove. This makes a very satisfactory and durable joint, the only objection being the necessity of springing it apart when removing a section for repairs.

Fig. 43 shows a joint in which the flanges are shrunk on the pipe, the ends of which are turned up as shown. No gasket is required in

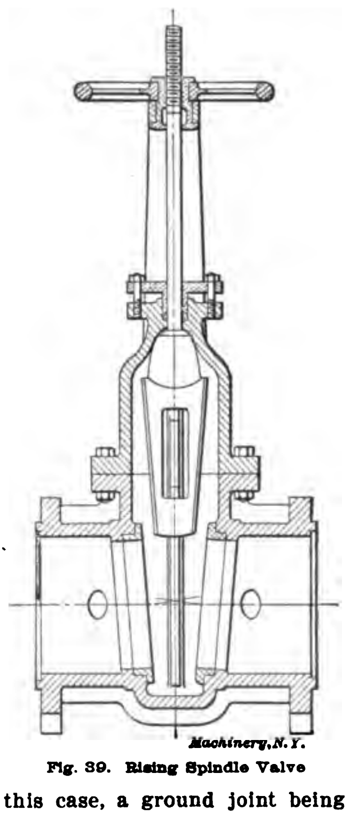

Fig. 39. Rising Spindle Valve

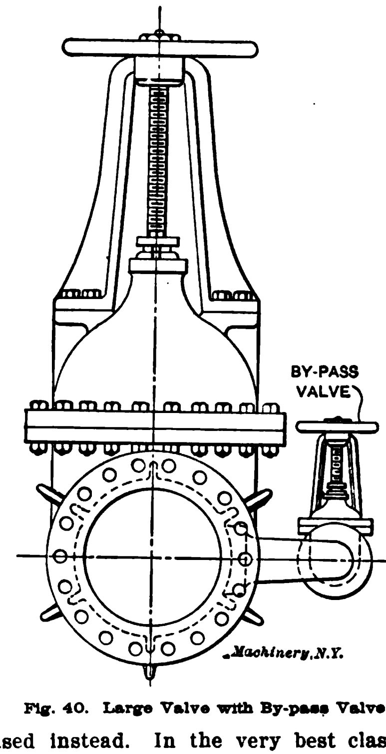

Fig. 40. Large Valve with By-pass Valve

this case, a ground joint being used instead. In the very best class of high-pressure work, where the cost is no objection, it is customary to use wrought-iron flanges welded to the pipe. This makes the tightest and most durable joint possible. One method of making a joint in a line of spiral riveted pipe is shown in section in Fig. 44. In other cases flanges are riveted to the pipe and bolted together with a gasket between them in the usual manner for low-pressure work. In the case of exhaust lines, the plain flange is used, with a vulcanized rubber gasket or one of similar material. Table IX gives data regarding flanges for low- and high-pressure work.

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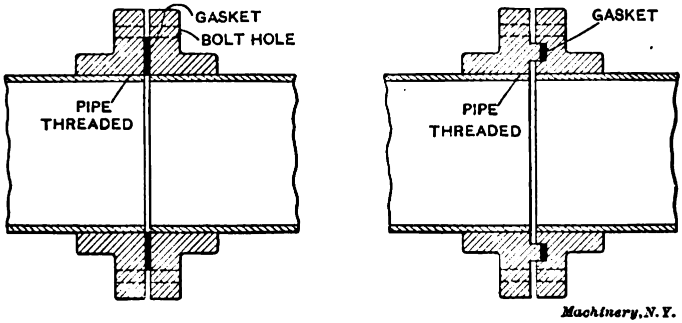
In the design of a system of piping, either for power or heating, especial care must be taken to allow for the strains due to expansion and contraction. Although this is of importance in heating work, it becomes doubly so in the case of high pressures, both because of the greater expansion due to the higher temperature, and the more serious results



Figs. 41 and 42. Types of Pipe Joints

in case of fracture under high pressure. Table X gives the expansion for each 10 feet in length for different steam pressures, in an atmospheric temperature of 50 degrees F.

There are three methods commonly used for taking up the expansion in pipes:

1. By using sweep bends in place of cast-iron elbows, and arranging the piping so as to provide the maximum amount of flexibility or spring.

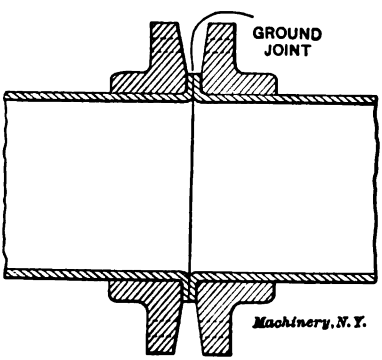


Fig. 43. Pipe Joint with Flanges Shrunk on the Pipe

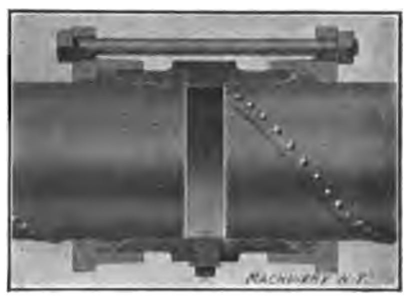


Fig. 44. Pipe Joint in Spiral Riveted Pipe Line

2. By the use of swivel joints.
3. By using expansion or slip joints.

The first method should always be employed, so far as possible, and should be supplemented by the other two where more flexibility is required. A swivel joint is shown in Fig. 46. The main and its continuation, together with the offset, are clearly indicated in the illus-

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tration, and any lengthening of the former is taken up by a turning movement at the two swivels which are packed to prevent leakage. A slight turning movement of this kind is kept tight more easily than a sliding movement.

A balanced slip joint is shown in section in Fig. 45; the path of the

TABLE IX. PIPE FLANGES

Diameter of Pipe	Diameter of Flange		Thickness of Flange		Number of Bolts		Diameter of Bolt Circle		Diameter of Bolts	
	Pressure		Pressure		Pressure		Pressure		Pressure	
	125 Pounds	250 Pounds	125 Pounds	250 Pounds	125 Pounds	250 Pounds	125 Pounds	250 Pounds	125 Pounds	250 Pounds
2	6	6 1/2	3/4	7/8	4	4	4 3/4	5	5/8	5/8
2 1/2	7	7 1/2	13/16	1	4	4	5 1/2	5 7/8	5/8	3/4
3	7 1/2	8 1/4	13/16	1 1/8	4	8	6	6 5/8	5/8	5/8
3 1/2	8 1/2	9	7/8	1 3/16	4	8	7	7 1/4	5/8	5/8
4	9	10	15/16	1 1/4	4	8	7 1/2	7 7/8	3/4	3/4
5	10	11	15/16	1 3/8	8	8	8 1/2	9 1/4	3/4	3/4
6	11	12 1/2	1	1 7/16	8	12	9 1/2	10 5/8	3/4	3/4
7	12 1/2	14	1 1/16	1 1/2	8	12	10 3/4	11 7/8	3/4	7/8
8	13 1/2	15	1 1/8	1 5/8	8	12	11 3/4	13	3/4	7/8
9	15	16	1 1/8	1 3/4	12	12	13 1/4	14	3/4	7/8
10	16	17 1/2	1 3/16	1 7/8	12	16	14 1/4	15 1/4	7/8	7/8
12	19	20	1 1/4	2	12	16	17	17 3/4	7/8	7/8

steam is indicated by the arrows. The joint is made tight by means of two glands with packing, and is balanced by exposing the end *A* of the inlet pipe to atmospheric pressure. A type of expansion joint

TABLE X. EXPANSION OF PIPE AT DIFFERENT TEMPERATURES

Pressure, Pounds Gage	Temperature, Degrees F.	Expansion in 10 Feet, Inches	Pressure, Pounds Gage	Temperature, Degrees F.	Expansion in 10 Feet, Inches
10	240	0.148	90	331	0.219
20	259	0.163	100	337	0.224
30	274	0.175	110	344	0.229
40	286	0.184	120	350	0.234
50	297	0.193	130	355	0.238
60	307	0.199	140	360	0.242
70	316	0.207	150	365	0.246
80	323	0.213	...	...	.....

sometimes used in large outbound exhaust pipes, where there is practically no internal pressure, is shown in Fig. 47. This form is particularly adapted to spiral riveted pipe, to which the flanges *A* are riveted. Flexibility is secured by means of a copper ring attached to the flanges by the cast-iron rings *B*, which are secured by bolts as shown.

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Steam and exhaust pipes should not only be strongly supported, but the supports should also be arranged to allow for the movement due to expansion and contraction. Overhead pipes, if not too large, are commonly hung from the ceiling construction by adjustable hangers. Fig. 48 illustrates a method of attaching a hanger to a brick wall by means of an iron bracket and anchor bolts. A similar type of hanger, clamped to the lower flange of an I-beam, is shown in Fig. 49. In both of these cases any movement of the pipe is cared for by the swinging of the hook upon the supporting rod. In Fig. 50 the hook is replaced by a

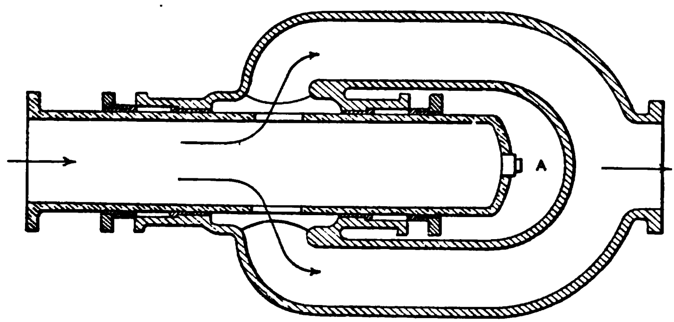

Fig. 45. Balanced Slip Joint

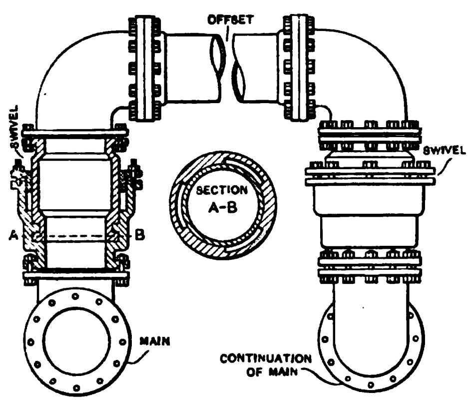

Fig. 46. Swivel Joint

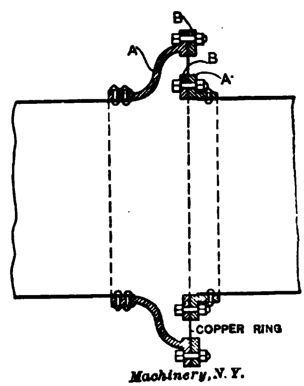

Fig. 47. Expansion Joint for Large Exhaust Pipes

bolt and nut, and flexibility is secured by a spherical washer beneath the nut, shown in detail in Fig. 51.

Pipes which run near the floor or over boiler tops are commonly carried on rolls of the general form shown in Fig. 52. These are made of cast iron, and are usually supported on brick piers.

An arrangement for carrying pipe lines in a trench is illustrated in Fig. 53. In this case the pipes are supported in loops of strap iron hung from an overhead cross-bar with wheels at each end, running

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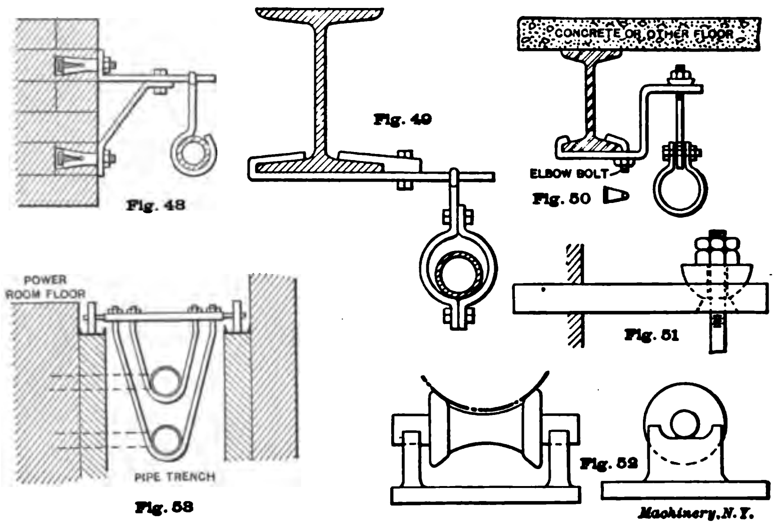
on channel iron tracks as shown. Any movement of the pipe due to expansion is taken care of by these overhead trucks.

Pipe Conduits

There are various ways of constructing underground conduits for carrying pipe lines from one building to another, or through basement



Figs. 48 to 53. Pipe Supports and Hangers

rooms where it is desired to keep them below the floor. In some cases concrete trenches are used covered with slate or slabs of concrete, while in others the mains are run inside of tile piping with cemented joints.

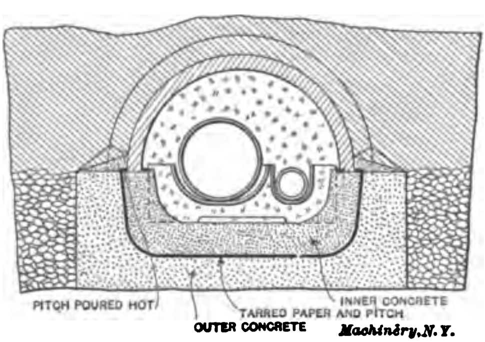


Fig. 54. Waterproof Pipe Conduit

A waterproof conduit of good design is shown in Fig. 54. The upper part of this conduit is formed by one-half of a tile pipe of suitable size, split lengthwise, while the lower part is made up of concrete. The joints are made water-tight by means of pitch and tarred paper, as shown. For heavy mains, electric cables, etc., it is necessary to construct tunnels of brick or concrete of sufficient size for a man to pass through when inspecting.

Insulation

All steam and exhaust piping should be protected with some good form of sectional covering to prevent loss of heat. In the case of high-

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pressure piping, there are two reasons for this: first, to reduce the condensation, and thus prevent useless waste of heat; and second, to keep the boiler and engine rooms as cool as possible. With the exhaust lines

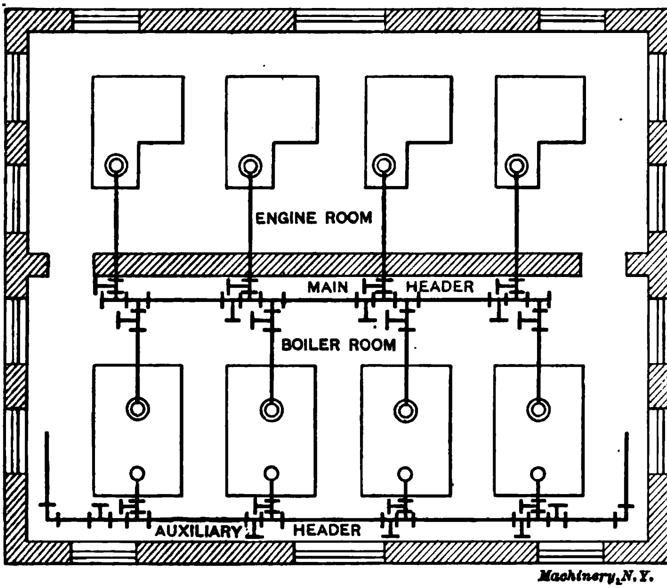

Fig. 55. Piping Arrangement of a Power Plant

the latter reason is the more important, unless the steam is utilized for a heating system. All apparatus such as feed-water heaters, sur-

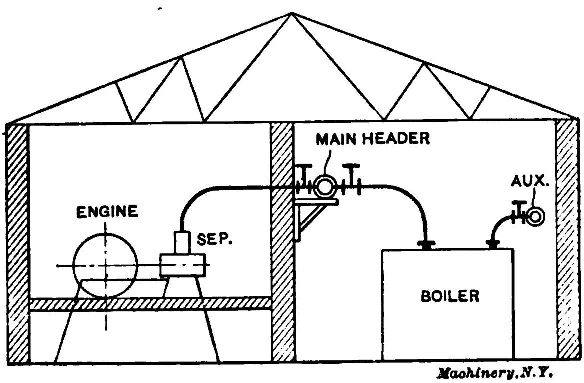

Fig. 56. Elevation of Power Plant in Fig. 55

face condensers, receiving tanks, etc., should also be covered in a similar manner.

Pipes are usually insulated with sectional covering provided with a canvas jacket and held in place by thin metal bands. Valves and fittings are commonly covered with a plastic material and finished with

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canvas, the same as the piping. In the highest class of work moulded covering is often used in place of the plastic material, so that the covering may be removed for purposes of inspection or repairs, and then be replaced without injury.

High-pressure Piping

Nearly all modern power plants are designed along two general lines, one of which is shown in plan and elevation in Figs. 55 and 56. In this arrangement the engines and boilers are placed back to back, with a fire wall between. This arrangement is very compact and reduces the distance from the boilers to the engines to a minimum. The main header is preferably located in the boiler room, as it may be the means of avoiding serious injury to the engines and electrical apparatus in case of accident, thereby allowing the plant to continue in operation

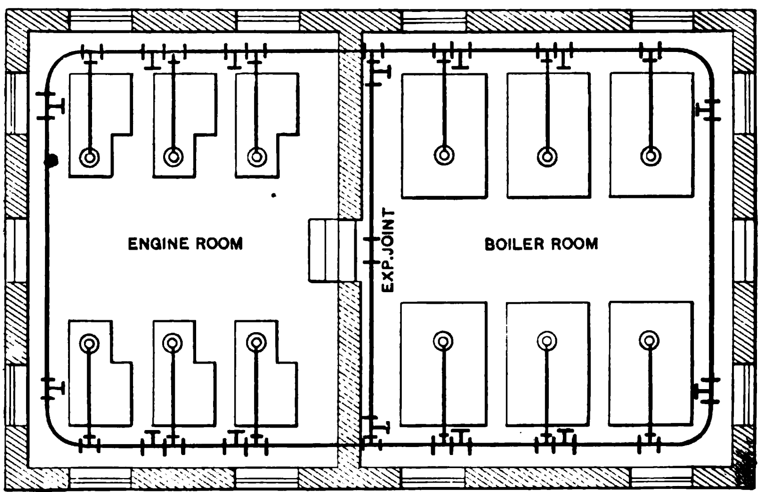

Fig. 57. Alternative Piping Arrangement for a Power Plant

after cutting out the damaged sections by means of the valves provided for that purpose. It is always best to use an independent steam header for the auxiliaries, such as pumps, heaters, etc., as shown in Fig. 55.

It will be noted in Fig. 56 that the level of the engine room is somewhat above that of the boiler room. This is a very desirable arrangement as it allows a space for condensers and exhaust piping below the engines. This makes it possible to keep the engine room cooler, prevents damage from steam and water in case of leaks, removes the heavy and unsightly exhaust piping from direct view, and facilitates the matter of drainage.

Flexibility is secured by using sweep bends in the boiler and engine connections with the main header, as shown in Fig. 56. Valves are so provided that any engine or boiler can be cut out of service indepen-

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dently of the others, and in addition to this, the main header is divided into sections.

In the second arrangement of power plants, the boiler and engine rooms are placed end to end as in Fig. 57, and the ring system of piping employed. Valves are so placed in the main as to divide it into sections which may be cut out in case of accident or repairs. In some plants the more important lines of piping are duplicated, making it practically impossible to put the apparatus out of service by an accident to the piping.

Pipe Sizes

There are various ways of computing the high-pressure pipe sizes in power plant work. In general, the velocity of flow should not exceed

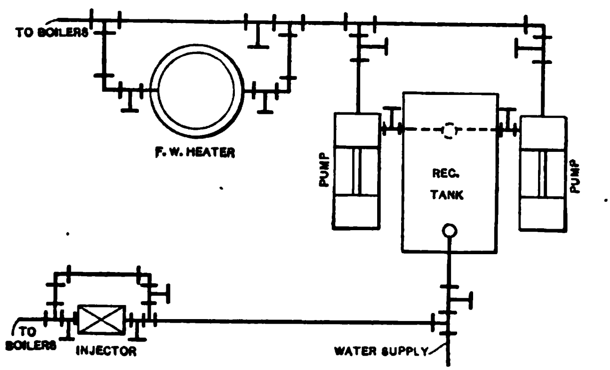

Fig. 58. Feed Piping for Non-condensing Plant

6000 feet per minute. A formula often used for determining the size of supply mains, when the length is not great, is given below:

$$d = D\sqrt{\frac{S \times \text{R. P. M.}}{36{,}000}} \qquad (13)$$

in which

d = diameter of steam pipe, in inches,
D = diameter of engine cylinder, in inches,
S = length of stroke, in inches,
R. P. M. = revolutions per minute of engine.

Feed Piping

Three typical layouts for feed piping are shown in Figs. 58, 59 and 60. The first of these applies to a non-condensing plant with a feed-water heater. The supply from the city main enters as shown, one branch leading directly to the boilers through an injector provided with a by-pass. The other branch leads to a receiving tank from which the water is pumped to the boilers as indicated. The feed-water heater is placed in a by-pass and can be used or not as desired.

In Fig. 59 the piping is arranged for a surface condenser. The branch leading to the injector is the same as before. The other branch

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goes directly to the pumps with an off-take to the hot-well provided with a float valve. The connections between the pumps and boilers, including the feed-water heater, are the same as before. The discharge from the air pump goes to the hot-well, from which it may be fed into the boilers by the pumps if desired.

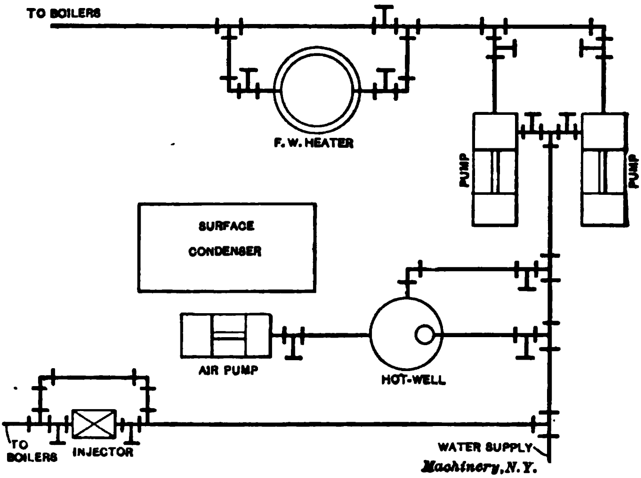

Fig. 59. Feed Piping for Plant with Surface Condenser

Fig. 60 shows a typical arrangement for a condensing system using a jet condenser, and having both primary and secondary feed-water heaters. The receiving tank and injector arrangements are the same as in Fig. 58, the only difference being that there are two heaters in-

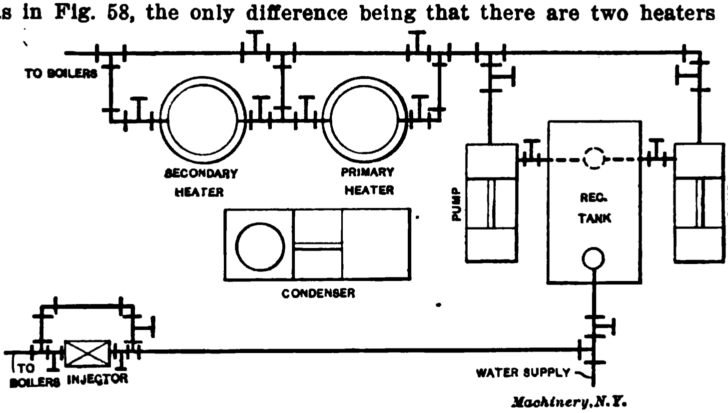

Fig. 60. Feed Piping for Plant with Jet Condenser

stead of one. The primary heater is placed next to the pumps and is supplied with exhaust steam at condenser pressure from the engines. The secondary heater is next to the boilers and is furnished with exhaust from the feed pumps and other auxiliaries. The discharge from the condenser pump is turned into the sewer.

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NUMBER 73

PRINCIPLES AND APPLICATIONS OF ELECTRICITY

By NEWTON HARRISON

PART I

STATIC ELECTRICITY—ELECTRICAL MEASUREMENTS—BATTERIES

CONTENTS

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CHAPTER I

STATIC ELECTRICITY

Greece, with her art, her literature and philosophy, has left her stamp upon all other great nations, whose destinies have been largely moulded by the thought which emanated from the classic times. Vast influences have sprung from her buried seed of learning, even though her knowledge was shrouded in the mists of mythology. Thales, the Greek philosopher, remarked upon the curious properties of amber. To him, a prototype of Greek paganism and metaphysical thought, there lay within this strange relic of primeval days a wonderful soul. The soul of amber, as it was called, gave evidence of its existence when the amber was rubbed upon the garments. A strange influence was emitted from the precious gum, which drew towards it light bodies, such as wisps of straw, for example. This unique property of amber was recorded by the sage, and handed down to other nations, to become, after the passage of more than 2000 years, the subject of new interest and inquiry, from a standpoint, however, which stripped it of its mythological character and fortunately gave rise to a series of new investigations of great interest and ultimate benefit to mankind.

The period of the renaissance proved an awakening, not only to the world of art and letters, but gave rise to a new manner of thinking, which ushered in the birth of science. Dr. Gilbert, one of the exponents of this new idea, physician in the reign of Queen Elizabeth, investigated the properties of amber in conjunction with a series of other substances, and thus was enabled to find in them all a similarity of effects which forever dissipated the doctrine of spiritual influences as far as this particular substance was concerned. The Greek name elektron, however, which means amber, has been preserved and embodied in the word electricity.

The question is often asked, "What is electricity?", and the answer generally given is ambiguous and misleading. Electricity, like light and heat, is simply a form of energy. The entire field of electrical engineering, with its immense scope and innumerable applications to domestic, municipal and industrial purposes, represents, in total, only an effort to produce an effect at a point more or less distant from the source of power, and to transmit and transform energy with this object in view.

The fundamental idea of energy is, in a sense, metaphysical, yet it is defined as the capacity of a body to do work. Force is defined as any cause that produces, stops, changes, or tends to produce, stop or change the motion of a body. Work is defined as the action of a force in overcoming resistance. There are, therefore, the ideas of energy,

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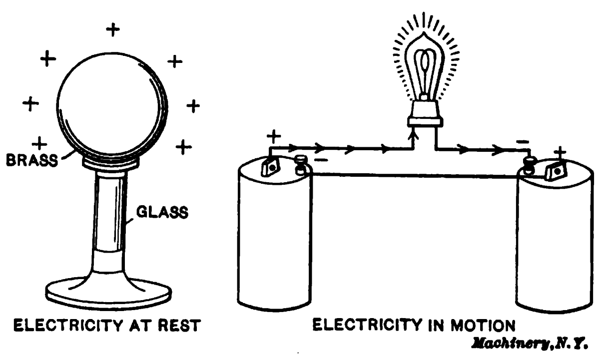
force and work, upon which the structure entitled the electrical science is reared and without which it is impossible to measure the relationship between cause or effect, or one form of energy and another, in an exact and practical manner.

To deal with the subject of electricity in an exact manner, it is necessary to base all units upon some foundation which can be considered as unchangeable. An international agreement has been reached in this respect, with the result that the units of length, weight and time which are employed, are the centimeter, gram, and second. The name given to the system based upon the use of these units is the absolute or C.G.S. system. From these units are derived all measurements of force or work by means of which the phenomena of electrical actions and reactions can be expressed.

Static Electricity

Electricity can be generally divided into two kinds—static and dynamic. Static electricity means electricity at rest. Dynamic elec-



Figs. 1 and 2. Examples of Static and Dynamic Electricity

tricity means electricity in motion. As an illustration of what is meant by static electricity, take a metal globe insulated by means of a glass support and charge it with static electricity. (See Fig. 1.) This is a case of electricity at rest. On the other hand, take a source of electric current such as a couple of dry cells and connect the terminals through a small lamp. (See Fig. 2.) In this case the electricity is in motion, and is thereby distinguished from the static. It is merely necessary to impart motion to a static charge to give it all the characteristics of dynamic electricity or of what is called a *current*. If the charged metal globe is allowed to discharge its electricity through a wire (see Fig. 3), it becomes transformed into dynamic electricity and exercises the same effects as an electric current. This has been noted a number of times in the case of lightning discharges, where melting, burning and decomposition have been caused by the escaping electricity, originally static in character, and for the instant possessing those qualifications which define it as dynamic.

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Producing Static Electricity

Nearly all chemical and physical changes produce electricity. Static electricity can be produced in great quantities by means of friction and by applying certain principles of static electricity to the construction of machines through which mechanical or muscular energy is transformed into static electricity. A common way of developing static electricity for experimental purposes, is to use a glass rod free from lead, and rub it with a silk handkerchief, or to secure a rod of hard rubber and rub it with a woolen cloth. If the air is dry, sufficient electricity can be obtained to produce decided reactions with small pieces of light paper, fragments of cork, etc. Benjamin Franklin in his experiments used a glass globe mounted on a horizontal axis, against which a rubbing cushion pressed, thus producing static electricity.

Two Kinds of Electricity

There are two kinds of electricity, called positive and negative, as may be ascertained by the following experiments: Take a glass rod

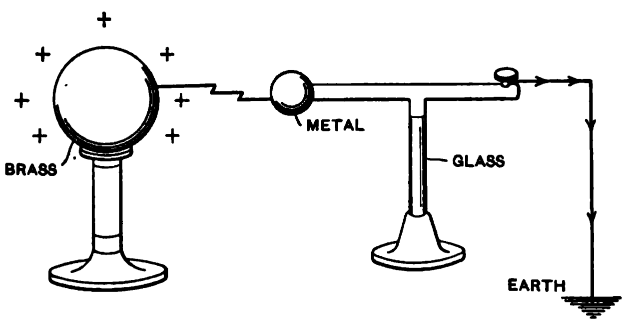

Fig. 3. Static Electricity being Discharged

and excite a charge on its surface by rubbing it with a silk handkerchief. Bring the end of the rod near a pith ball mounted on an insulating support and hanging from a delicate silk thread, as shown in Fig. 4. On bringing the charged glass rod near the pith ball, it will be attracted, but on touching the rod it will be instantly repelled, assuming the position marked 3. The process may be repeated with a rod of hard rubber on which a charge has been excited by means of a woolen rag. On bringing the hard rubber rod near the pith ball it will be attracted and repelled in exactly the same manner. The positions assumed by the pith ball are relatively 1, 2 and 3 with either rod. The fact to be observed particularly in the course of such an experiment, is that the pith ball, though showing every sign of marked repulsion to the charged glass rod in the first case, instantly flies to the charged hard rubber rod in the second case; and if the experiment is then repeated with the glass rod it will be seen that the pith ball strongly repelled from the hard rubber rod will now be attracted by the excited glass rod. The results can be tabulated as follows:

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1.—Glass rod: Pith ball attracted, then repelled.
2.—Rubber rod: Pith ball attracted, then repelled.
3.—Glass rod: Pith ball attracted, then repelled.
4.—Rubber rod: Pith ball attracted, then repelled.

In other words, it is evident that the electricity in the pith ball, communicated to it in the first place by the glass rod, causes repulsion, and that the same electricity in the pith ball causes it to be attracted by the rubber rod, though subsequently repelled; and in this manner the operation can be kept up, showing that what the glass rod repels, the rubber rod attracts, and *vice versa*.

The explanation of this phenomenon lies in the assumption of two kinds of electricity, called positive (+) and negative (—), produced by the glass and rubber rods, respectively. When the glass is rubbed with silk, positive electricity is developed on the glass. When the rubber rod is rubbed with flannel, negative electricity is developed on

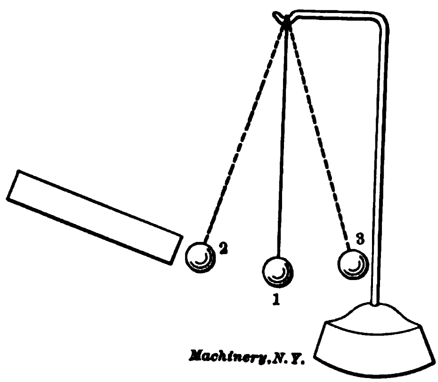

Fig. 4. Experiment Showing the Presence of Positive and Negative Electricity

the rod. Bringing the glass rod near the pith ball causes the pith ball to be attracted; it touches the glass rod, and is repelled. The repulsion occurs because it has taken up some of the electricity of the glass rod, which is positive. The negatively charged rubber rod is brought near, and the pith ball is attracted. This occurs because the pith ball and the rubber rod hold different kinds of electricity, or present different phases of electrical energy. After the pith ball touches the rubber rod and has had some of the negative electricity transmitted to it, it is repelled. The entire process is due to the operation of two simple laws as follows:

Law I.—*Unlike charges attract each other.*

Law II.—*Like charges repel each other.*

When the pith ball touches the glass rod, the positive electricity in both glass and ball causes repulsion. The negative electricity in the rubber can then attract, but when contact occurs also repels. Thus the various positions of the pith ball, 1, 2 and 3, are adequately explained after contact takes place, and when a body charged with an

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opposite kind of electricity is brought near the pith ball. This explanation will hold in all cases where two charges of electricity can affect each other. The character of these charges must be determined, and then a rational conclusion drawn, based upon the two laws as stated. Before a further advance is made in the study of this subject it is necessary to arrive at some conclusion regarding what may be called a unit charge of electricity.

Unit Charge of Electricity

To measure static electricity correctly, a simple experiment can be tried or imagined in the following manner: Two spheres (see Fig. 5) of 1 centimeter radius are placed 1 centimeter away from each other. Each of the spheres is charged with positive electricity, imparting to each exactly the same quantity. If the condition is imposed that the spheres each possess an equal charge of electricity, then, when they

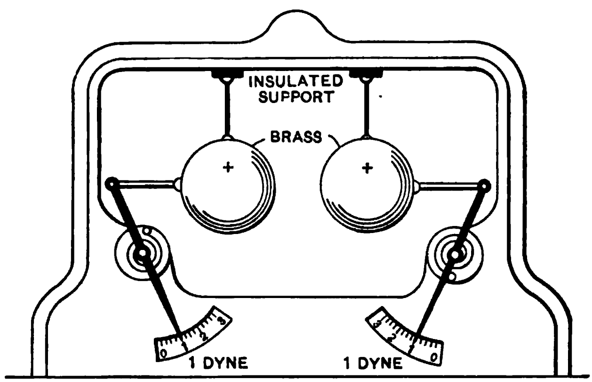

Fig. 5. Mechanical Illustration of the Unit Charge of Electricity

repel each other with the force of one *dyne*, each sphere possesses a *unit* charge of electricity. To fully explain the meaning of this it is necessary to define a dyne.

A dyne is the force required to impart to a mass of 1 gram the velocity of 1 centimeter per second. It is the same as though the amount of force were measured that is required to lift a weight of 1 pound 1 foot per second, only the force in the case of a dyne is much smaller, and is the result of the adoption of the C.G.S. system as the basis for all units. A unit of electricity, commonly called a unit quantity or unit charge, is named a coulomb in honor of a distinguished investigator of that name. It is defined as that quantity of electricity on the surface of a sphere of 1 centimeter radius, which will repel a similar and equal quantity on a sphere of 1 centimeter radius at a distance of 1 centimeter with the force of 1 dyne.

Static Charges outside of Bodies

If a sphere is charged with electricity an examination of it will show the charge distributed equally on the outside. If the sphere is hollow

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(see Fig. 6), an examination of it when charged will disclose the same state of affairs, namely, that there is no electricity inside the sphere, the charge being entirely outside. Michael Faraday made note of this fact, and experimented with what is called a Faraday cylinder for the purpose of illustrating this idea. It will be seen in Fig. 7 that when the cylinder is charged, the pith balls inside show no sign of repulsion, but the pith balls outside violently repel each other. This is due to the presence of electricity only on the outside of the cylinder; were there any inside it would give evidence of its existence, by causing repulsion between the inner pith balls, but as this is not so, the opposite conclusion is inevitable.

A network of wires forming a cage would therefore be a great protection against heavy charges of electricity. If a sort of electric cage armor of this description were constructed, enormous charges of electricity could be directed at it without producing the slightest effect upon those within. In large cities with modern steel frame buildings, considerable protection is afforded from this source alone against lightning. The steel frame also serves as an excellent ground connection during electric storms.

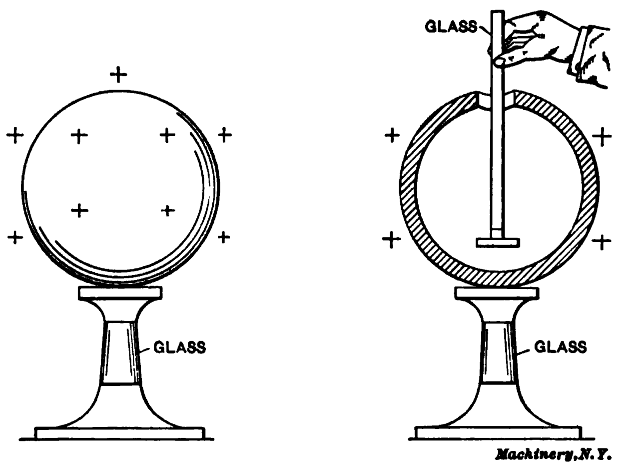

Fig. 6. Solid and Hollow Spheres, Showing Charge on the Outside

Electrostatic Induction

A keen mind will not be contented with the statement made regarding a charged rod and a pith ball. The inquiry which will arise is this: Why does the pith ball in the first place move toward the charged glass rod? It is to be remembered that the pith ball was perfectly neutral in the first experiment, yet it was immediately affected by the presence of a charge in its neighborhood. How can a charged body affect a neutral body? Why should a pith ball absolutely devoid of any trace of electricity be attracted by a charge of electricity? The answer is as follows: The charged body affects the condition of the

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pith ball and develops in it both positive and negative electricity. (See Fig. 8.) From this fact a general principle can be stated—that induction occurs between a charged body and a neutral body across the empty space between them. In some remarkable way an influence is promulgated from every electric charge in such a manner that all bodies far and near become possessed of two kinds of electricity. By giving to this the name of electrostatic induction, it must not be un-

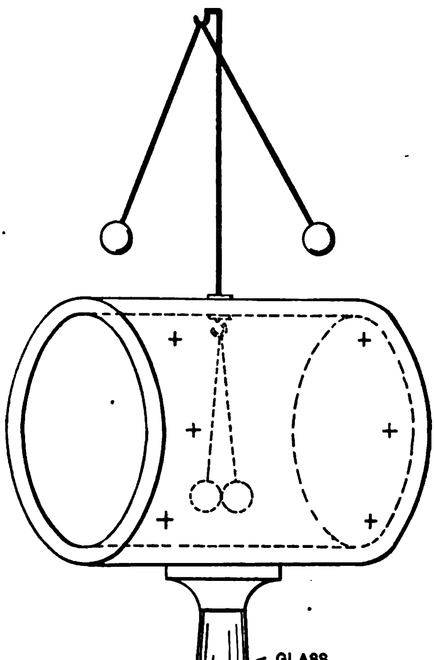

Fig. 7. Faraday Cylinder, Showing Electricity on the Outer Surface only

derstood that the phenomenon is explained; but such facts as can be deduced from experiments which prove the presence of induction are employed for the purpose of investigating other results, the causes of which would otherwise be a matter of great doubt.

Continuing the discussion relating to the pith ball, it is now easy to see why it was attracted by the charged rod. It simply obeyed the law "that unlike charges attract each other," and for this reason if the rod was positively charged it attracted the negative electricity in the pith ball developed there by induction. Another question which will arise, however, is this: Why does the pith ball move, even though

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it is attracted, when it also carries a charge which repels? This is because the attracting charge is nearer to the charged rod than the repelling charge and therefore one force is a little greater than the other.

This idea can be best represented by two metal plates, one of which is insulated and rests on an insulated support, while the other is supported by means of a spring balance, as shown in Fig. 9. Before the lower plate is charged, the force indicated on the spring balance will be merely that of the weight of the upper plate.

When the lower plate is charged with positive electricity, induction takes place between it and the upper plate. The lower surface of the upper plate develops a charge of negative electricity, while an *equal* quantity of repelled positive electricity accumulates on the upper surface of the upper plate. The scale will indicate a greater force than before and the difference between the apparent weight when affected inductively and the actual weight of the plate is the extent of the attraction. This, of course, represents the difference, as well, between

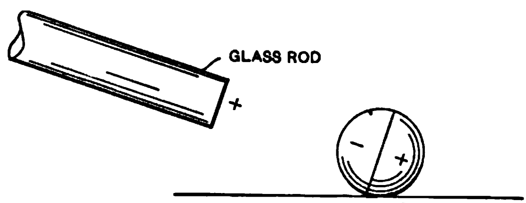

Fig. 8. Induction between Pith Ball and Glass Rod

the attraction of the positive and negative and the repulsion between the positive and positive electricity of the two plates. If sheets of different materials such as glass, hard rubber, paraffin, etc., are interposed between the two plates it will be noted that the balance will change its record in each case.

Insulators and Dielectrics

The change in the record of the spring balance would be due to the fact that different insulating materials, such as those enumerated, cause different degrees of induction to occur between the plates. This power of a body to allow induction to occur through it is called its inductive capacity and such bodies are called *dielectrics*. Therefore when the induction is greater, the balance records a greater pull, and when it is less the reverse is true. The amount of induction occurring through air is taken as the standard and is called 1. With reference to this the inductive capacity of other bodies is noted.

When a body conducts electricity it is called a conductor, and when it does not conduct electricity the name insulator or non-conductor is employed. One of the best conductors is silver and one of the best insulators is dry air. Between these two are a series of substances which include metals, earths, water, etc., which embrace all grades of

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conductivity. For this reason they are grouped in such a manner that they comprise the following:

Partial conductors such as metals, wood or earth.

Non-conductors, such as rubber, glass or porcelain.

When lightning leaps through the air it breaks down the insulating properties of the air because of the tremendous tension existing between two opposite charged bodies. When the accumulated charges of electricity reach a certain point, the electrical pressure becomes so great that the insulation is rent by what is called a "disruptive discharge."

Electrophorus

To produce static electricity continuously without having to resort to the rather primitive method of rubbing a rod of glass or hard rubber with a silk or woolen rag, a device is employed which involves the

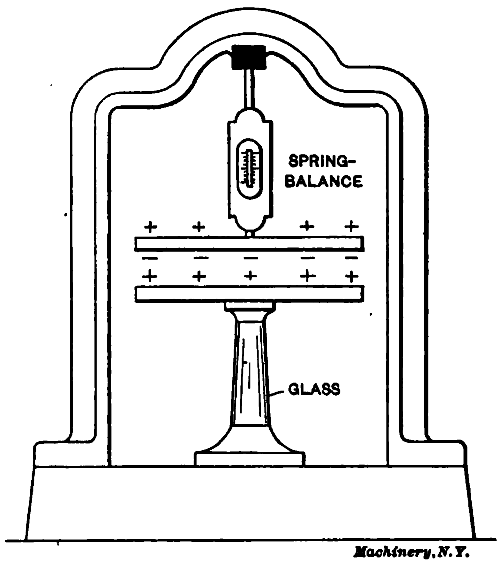

Fig. 9. Induction between a Charged and a Neutral Body, and the Method used for Measuring the Attraction

action of the two fundamental laws of static electricity and the principle of electrostatic induction. It is called the electrophorus and consists of a plate of hard rubber or resin on which rests a detachable brass plate with an insulated handle.

The hard rubber plate is beaten with a piece of cat's fur or a woolen rag and becomes strongly electrified. The brass plate is then rested upon the rubber plate and the finger then placed upon the brass plate for an instant. If the brass plate is lifted up carefully by its handle and the knuckle presented to it, a spark will show that quite a discharge has taken place. If the plate is put back, then touched with the finger and removed and discharged and the operation repeated a

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dozen times, it will become evident that in this device electricity can be obtained continuously without applying friction more than once to the under plate.

In the first place, when friction is applied, negative electricity is developed. This charge acts by induction on the brass plate resting on it and positive and negative electricity appear. The positive electricity is held on the under side of the brass plate by induction and is called a *bound* charge. The negative is repelled to the upper surface of the brass plate and is called a *free* charge. The free charge may be removed by touching the plate with the finger. When the plate is lifted away by its handle, the bound positive electricity becomes free, because it is removed from the inductive influence. It can be discharged by presenting the knuckle and the device is then ready for a repetition of the process.

The question is asked, "Why does induction take place when the brass plate *rests* on the rubber plate?" The answer is that a film of dry air acts as insulation between the two plates. The inequalities of

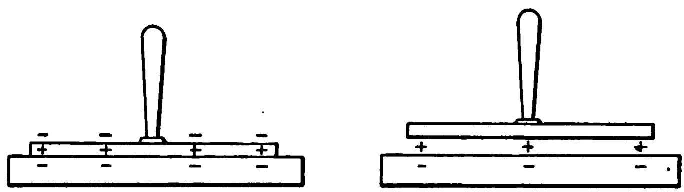

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Fig. 10. Electrophorus with Plates in Contact, and with Plates Separated and the Free Electricity Removed

surface account for this; otherwise, if the surfaces were absolutely flat and therefore in intimate contact, the negative electricity of the under plate would pass into the upper brass plate and there would be conduction instead of induction.

The Leyden Jar and Condenser

Electricity can be accumulated or condensed so that small quantities regularly supplied to a properly constructed device can be gathered into one large charge. The original name for such a device was a Leyden jar, but in its more modern form it is called a condenser.

The town of Leyden, Holland, was, according to tradition, the scene of the following incident about two centuries ago: A beaker of water holding a metal stirring rod rested on a stand near an electrical machine. Sparks from the machine entered the rod and charged the water. When the beaker was lifted by the philosopher's assistant with one hand, and the other touched the rod, a terrible shock was experienced by him, and the beaker fell to the ground. This meant the discovery of a means of condensing a series of small charges, so that when so held they were capable of discharging in one great flash. A Leyden jar, Fig. 11, consists of an inner and outer coating of tin foil attached to a glass beaker. A metal rod with a knob at its outer end and a chain at its inner end, is mounted in the center of a well-var-

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nished cork inserted in the mouth of the beaker. When positive electricity enters the knob, the inner tinfoil coating is charged. The outer tinfoil coating is acted upon by induction and its inner surface becomes negative and its outer surface positive. The outer surface can be touched with the finger and the free positive electricity removed. As the jar now stands it contains positive electricity inside and negative outside, and it can be repeatedly charged with small amounts of electricity, until a considerable charge has been accumulated. The two plates of the electrophorus in Fig. 10 act in the same manner, and merely re-

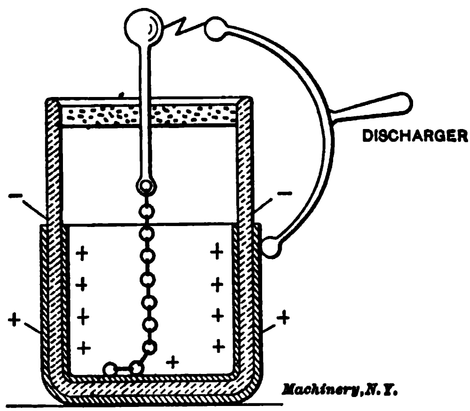

Fig. 11. Diagrammatical Representation of the Leyden Jar

present the two tinfoil coatings in a different position. In this manner electricity is condensed, or, expressed in a more scientific manner, *the potential is raised.*

Principle of the Condenser

If a closed tank with one inlet is pumped full of gas, the gas pressure rises. The gas may enter in small quantities until the tank contains gas at the same pressure as the working pressure of the pump; then the action ceases. A condenser is an electrical tank in which the electrical pressure (measured in *volts*) rises as more electricity enters. The correct expression is that the potential rises as the condenser is charged. In order to be accurate, and thus have a system by which measurements can be made, the units of potential and capacity are defined with reference to the condenser as below.

Definition of the Farad

A condenser has a capacity of one *farad*, if, when charged with one *coulomb* of electricity it has a difference of potential of one volt. This means, for instance, that if a metal tank takes in a cubic foot of air and then shows 15 pounds pressure, the tank has a capacity of one cubic foot. In the same sense if the electrical tank takes in a coulomb and shows a pressure of one volt, its capacity is one farad. The capacity

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is determined by the pressure developed by a certain quantity of electricity in the condenser. This is expressed by the simple formula:

Quantity = pressure × capacity.

For instance, if a condenser had a capacity of 1 farad it would have 1 volt difference of potential with 1 coulomb, 2 volts with 2 coulombs, 3 volts with 3 coulombs, etc. The idea is relatively the same as if 1 cubic foot of air is forced into a tank of 1 cubic foot capacity, the pressure being 15 pounds; with 2 cubic feet, 30 pounds; with 3 cubic feet, 45 pounds etc.

When sheets of tinfoil and paraffined paper are arranged in alternate layers, and a tongue of tinfoil allowed to project for the purpose of making connections from each tinfoil sheet in such a manner that the projections of all the positive sheets are easily connected together as well as the projections of all the negative sheets, as shown in Fig. 12, then a practical condenser is obtained which can be used for exact tests when its capacity has been determined. The farad is such a

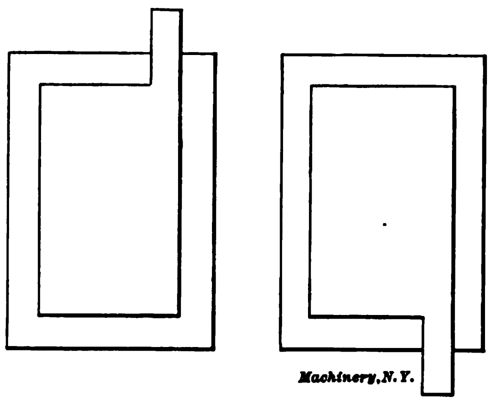

Fig. 12. Plates of Condenser, Showing Paraffined Sheet with Tinfoil having Projection for Connections

large unit and so unattainable in practice that condensers are built on the basis of one one-millionth of a farad. This fractional part of the original unit is called a microfarad. A condenser of a microfarad capacity is about the size of a cigar box, but, of course, such a comparison is not very exact, because the capacity of a condenser depends upon the area of the tinfoil sheets, the nature of the dielectric, and the thickness of it.

Connecting up Condensers

Condensers may be connected in series for high potential effects and in multiple for low potential effects. By this is meant that condensers in series give high pressure (voltage) and small quantity, while those in multiple give large quantity and little pressure. This idea is represented by the diagram in Fig. 13, where the condensers are connected in series. Here the + and — poles are connected to-

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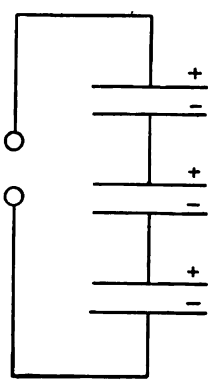
gether and by that means the potentials of the various condensers. In Fig. 14 the condensers are connected in multiple. All the positive poles of the condensers are connected together and all the negative. The total capacities are obtained as follows:

Condensers in Multiple.—Add the capacities of the various condensers together; for instance, if they are of 1, 2 and 3 farads capacity, respectively, the total would be 6 farads.

Condensers in Series.—The total capacity of condensers in series is equal to the reciprocal of the sum of the reciprocal of the capacities. Turned into arithmetic this rule appears as follows:



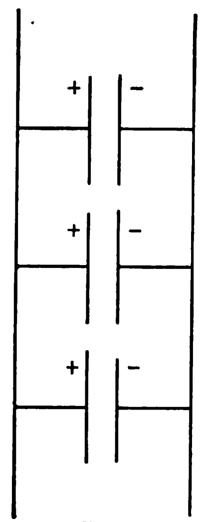


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Fig. 13. Condensers in Series Fig. 14. Condensers in Multiple

$$\text{Total capacity} = 1 \div \left(\frac{1}{\text{capacity of 1st condenser}} + \frac{1}{\text{capacity of 2d condenser}} + \frac{1}{\text{capacity of 3d condenser}} \text{ etc.} \right)$$

In the case mentioned above the total capacity would be:

$$\frac{1}{\frac{1}{1} + \frac{1}{2} + \frac{1}{3}} = \frac{1}{\frac{11}{6}} = \frac{6}{11} \text{ of a farad.}$$

Interesting examples of condenser action are afforded by a thunder storm. In this case the action may be merely between clouds. One cloud is heavily charged with positive and the other with negative electricity. When they approach, the clouds develop a high potential at the points nearest to each other, and the air resistance is broken down

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by a blinding flash. When a condenser is discharged by a wire leading from one pole to the other the principle is the same. If the electrified cloud is over a church steeple or a high tree, induction takes place. If the cloud is positive, the high structures underneath, and, in fact, the whole area exposed, become negatively charged. When the strain becomes so great that the inductive influence breaks down the integrity of the resistance between, lightning appears; and as a natural consequence of the discharge, the thunder follows. Lightning is practically instantaneous as far as the eye is concerned. Thunder, however, travels at the rate of 1100 feet per second, or about 1 mile every 5 seconds. By noting the number of seconds between the flash and the thunder, a fair estimate of the distance at which the disruptive discharge took place can be obtained.

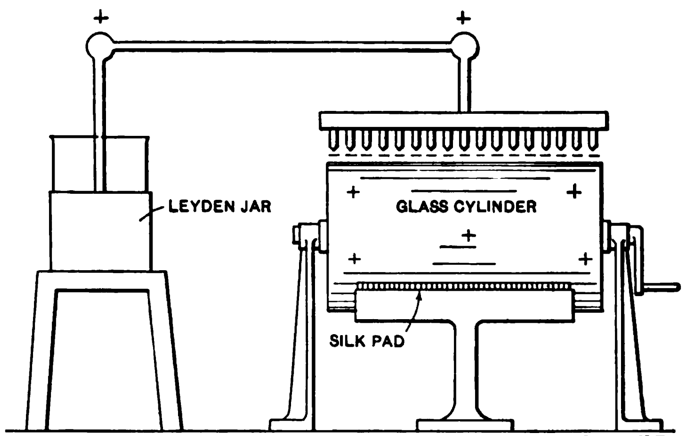

Fig. 15. Frictional Machine for Producing Small Quanities of Electricity

It is interesting to know the cause of the so-called splitting and breaking effects of lightning. If a tube filled completely with water and sealed, is exposed to a static discharge of sufficient force, it will break into pieces. This is due to the steam and gases of decomposition produced by the electricity in passing. The induction between the water inside, and the charge outside thus breaks down the glass wall between. With a tree, however, the wood cells contain moisture which is suddenly transformed into high pressure steam when the lightning passes. The effect of this is an internal disruption similar to a series of miniature boiler explosions, and the tree is necessarily split in two.

Waves Produced by Condensers

When a Leyden jar or a condenser is discharged it produces a tremendous disturbance in the ether. This disturbance appears in the form of waves, known by the name of Hertzian waves, and their application for the transmission of intelligence without wires is known as wireless telegraphy. If a large Leyden jar, or a static machine, is

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allowed to produce a series of discharges in the center of a room, it can be proven that millions of waves are set into motion in the room, pass through the walls and reach out over miles of distance through all sorts of obstacles such as other buildings, hills, etc.

A wire stretched around the room with fine saw cuts in it, thus dividing it up into sections, will exhibit small sparks between the edges of the cuts when a Leyden jar is discharged as described. This is due to the waves striking the wire, producing electricity in it, and appearing as minute sparks in a darkened room. Carrying out the idea with a sheet of tinfoil on a glass plate, the tinfoil divided by fine saw cuts, provides a device by which waves can be detected still further away. It is but a step to inclose fine metal filings in a glass tube with a metal plug at each end. This will detect waves at a great distance away from their source and if used in conjunction with a few cells of battery, a telegraphic relay, and sounder, we have the essential elements now in use for wireless telegraphy.

Frictional and Induction Machines

Machines producing static electricity may be divided into two classes—frictional and induction machines. The first type is but little used in the laboratory, but consists of a cylinder of hard rubber or glass rotated against a buffer or rubber of flannel, wool or silk, as shown in Fig. 15. A metal rod is placed near with teeth mounted in it almost touching the cylinder. Rotation of the cylinder produces positive electricity on its surface as it is rubbed by the pad. The teeth or points of the rod "blow" bound negative electricity on the glass, and, in consequence, an equal amount of free positive electricity is collected by the Leyden jar. This constitutes the so-called frictional machine in which, as can be seen, induction is an important factor. If the cylinder is replaced by a device which has its charge reinforced by *induction* alone, then the pure type of induction machine appears as represented by those machines bearing the name of Holtz, Ranney, Wimshurst, etc.

An interesting feature of induction and frictional machines is the fact that toothed rods keep the surface of the glass plate or cylinder neutralized. For instance, in the case given, as the glass cylinder rotates, the excited surface of the glass is brought opposite the row of teeth, which blow a stream of negatively charged particles of air on the retreating portion of the cylinder. This neutralizes it before it passes under the silk pad again.

It must be understood that the action of a point is to discharge electricity. The air particles in contact are charged and repelled, and as this is a continuous action it is evident that by this process the charge of a pointed object is quickly dissipated unless as rapidly supplied.

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CHAPTER II

ELECTRICAL MEASUREMENTS

Electrical measurements do not consist entirely of measurements of the amount of pressure (volts) or current (amperes) in a circuit. The process is more extensive than this and embraces the measurement of resistance, power, induction, magnetic flux, etc. In other words, under the title of electrical measurements may be included a great variety of tests in electricity and magnetism, many of which are of such great importance that it may be said that the very science of electrical engineering itself depends upon them for its existence. In the following, however, we shall deal only with the very simplest electrical measurements.

The corner stone of the science of electrical measurements rests upon a knowledge of what is known as Ohm's law. This law states that *the current is proportional to the electromotive force and inversely proportional to the resistance.* This law makes it possible to find any one of the three factors, amount of current, electromotive force, and resistance, when two of them are known. For instance, when resistance and current are given, electromotive force is found; when electromotive force and current are given, resistance is found; when electromotive force and resistance are given, current is found. The three quantities whose relationship can be expressed as indicated are thus:

1. Resistance, given in *ohms*.
2. Current, given in *amperes*.
3. Electromotive force, given in *volts*.

Ohm's law may be expressed arithmetically as follows:

To get volts, multiply amperes by ohms.

To get amperes, divide volts by ohms.

To get ohms, divide volts by amperes.

Expressed as formulas, these rules would be:

$$E = C \times R \qquad (1)$$

$$C = \frac{E}{R} \qquad (2)$$

$$R = \frac{E}{C} \qquad (3)$$

in which

E = electromotive force in volts,

C = current in amperes,

R = resistance in ohms.

To illustrate the application of Ohm's law, the following examples are given:

Example 1.—Find how many volts are required to send 10 amperes

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through a resistance of 100 ohms. In this case the volts are to be found, and the two values given must be multiplied together:

Volts = amperes × ohms = 10 × 100 = 1000.

Example 2.—Find the number of amperes passing through a lamp taking 110 volts, whose resistance is 220 ohms. According to the law as expressed by the rules just given, we have:

Amperes = volts ÷ ohms = 110 ÷ 220 = ½.

A fact which may be mentioned is that an incandescent lamp has a high resistance when cold, and a much lower resistance when hot. A resistance test would show that the lamp when cold has a resistance of 450 ohms, while at incandescence the resistance falls to 220 ohms.

Example 3.—Find the resistance of a coil of wire which takes a current of 2 amperes and a pressure of 110 volts. According to our rule,

Ohms = volts ÷ amperes = 110 ÷ 2 = 55.

These are the simplest illustrations of Ohm's law as employed by electrical workers all over the world. The examples may be considered as characteristic of the most important forms in which the law appears. It undergoes other changes in alternating current theory, because of the fact that additional influences are operating besides those ordinarily at work. The above forms would therefore be inapplicable to circuits carrying variable and alternating currents.

Ohm's Law for an Instantaneous Current

When a current is turned into a circuit for an instant and turned off, or when a current is first sent into a circuit, the current for a short period of time is not exactly equal to the volts divided by the ohms. There seem to be other influences at work which partially arrest the free flow of the current. It cannot be said that this influence is due to the resistance of the wire, because if this were the case, Ohm's law would hold true in every sense of the word. The difficulty, however, is not so much inside the wire, but is due to outside influence. This, it seems, acts in such a manner that a current cannot be instantaneously sent into a wire at its full strength, neither can it be instantaneously cut short. The wire possesses the power of developing, through this external influence surrounding it, *an electromotive force of its own.*

When the blacksmith strikes the anvil, the hammer flies back. In a sense, when a current strikes a circuit, the circuit strikes back. The sound may be absent, and there may be no visible signs of this reaction, but it is always there. From a scientific standpoint, it is said that the magnetism around the wire, which surrounds it when a current flows, momentarily develops this counteracting influence. It acts against the *incoming* current, checking it, and consequently only permitting it to rise to its full value in a certain period of time; or it acts with the retreating current when the circuit is opened, augmenting its pressure at the last moment. It had been noted for quite some time, before an examination of the conditions had been made by eminent physicists and mathematicians, that rapidly changing currents

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did not seem to flow in obedience to Ohm's law. Neither did Ohm's law, as then understood, coincide in its results when applied to those obtained with a current turned rapidly on or off. The fact that the current took an appreciable time to rise to its full value and did not immediately cease in a circuit opened and closed, gave room for thought. It soon became evident that the simple form of Ohm's law for these conditions would not do. It could be correctly applied in the case of a continuous current, but not in the case of either an *instantaneous* or an *alternating* current. Helmholtz interpreted Ohm's law in a new form, in which time is considered, and the influence external to the wire called self-induction. The Helmholtz equation, as it is called, is therefore a form of Ohm's law by which the current can be ascertained at any instant. In the equation expressing it, self-induction is expressed or measured in *henries*.

The Helmholtz Form of Ohm's Law

Helmholtz gave Ohm's law as stated, but he added a modifying clause, so to speak. He adds to the formula a parenthesis by which the fraction must be multiplied to obtain exact values for any condition of the circuit or current. The formula then takes the following form:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}\left(1 - e^{-\frac{\text{Ohms of circuit}}{\text{Self-induction of circuit}} \times \text{Time in seconds}}\right)$$

Written with symbols, Helmholtz's interpretation of Ohm's law for the current at any instant is:

$$C = \frac{E}{R}\left(1 - e^{-Rt \div L}\right)$$

In this formula, e is the base of the Napierian logarithms*; L is the self-induction in henries, and t the time in seconds.

To illustrate, make

$E = 100$ volts.

$R = 20$ ohms.

$L = 2$ henries.

$t = 5$ seconds.

Then e with its exponent becomes equal to $\frac{1}{e^{50}}$, which is practically equal to zero. This would leave $C = E \div R$, with the quantity inside of the parenthesis $= 1$. Hence, when the time during which the circuit is closed is prolonged, as in this case, to 5 seconds, the simple form of Ohm's law applies without modification.

Form of Ohm's Law for Alternating Currents

The influence of self-induction has been referred to in the Helmholtz form of Ohm's law. From this form of the law another expression has been obtained, which is given in a more practical form. In this new expression or formula, the effects of self-induction and the

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* See MACHINERY'S Reference Series No. 53, Use of Logarithms and Logarithmic Tables, page 16.

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frequent changes of the current are given such form that simple calculations can be made. When a current is started in a circuit, all of the disturbing effects are present whether the current is continuous or alternating. If the current is alternating in character, the more rapidly it reverses its direction in a second, the more of this reaction takes place in the circuit. The extent of this impeding influence is given by the formula as follows:

$$I = \sqrt{R^2 + p^2 L^2}$$

in which

R = resistance in ohms,
L = self-induction in henries,
$p = 2 \times \pi \times$ the frequency per second,
I = the impedance in ohms.

As a practical example of the use of this formula, the question might be asked: What is the impedance of a circuit (see Fig. 16), in which the resistance equals 5 ohms, the frequency 100 per second and the henries 2? Then

$R^2 = 5 \times 5 = 25,$
$p^2 = (2 \times 3.1416 \times 100)^2 = 394{,}800$, approx.
$L^2 = 2 \times 2 = 4.$

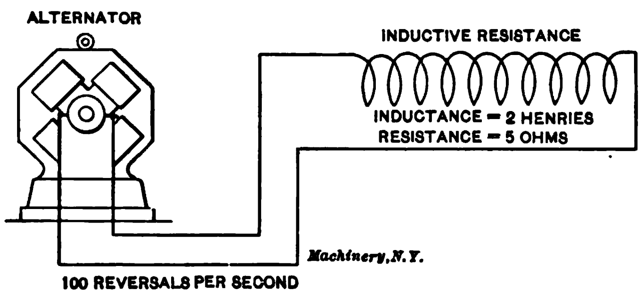

Fig. 16. Illustrating a Problem in the Calculation of Impedance in Alternating Currents

Then $R^2 + p^2 L^2 = 25 + 394{,}800 \times 4 = 1{,}579{,}225$, and the square root of this number equals 1257 ohms. The comparison of the effect of the resistance of 5 ohms and the effect of the impedance in total shows how the ordinary resistance may be disregarded altogether when the frequency of an alternating current is high or the self-induction in the circuit is high. The actual resistance having been substituted for by the false resistance, Ohm's law for alternating currents will be

$$\text{Current} = \frac{\text{electromotive force}}{\text{impedance}}, \text{ or } C = \frac{E}{I}.$$

If the current is not alternating, and therefore, there is no value to insert in the impedance formula for frequency, then the formula is simply a direct expression of Ohm's law. For instance, if there were no frequency, $p^2 L^2$ disappears, and the square root of R^2 is R. The

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formula then becomes $I = R$, and we have $C = \frac{E}{R}$, which is the original familiar form of Ohm's law. The two forms of Ohm's law as given by Helmholtz, and with respect to the resistance or impedance to alternating currents, both become transformed into Ohm's original form when the time is prolonged in one case, and the frequency or inductance disappears in the other.

Measurement of Resistance

One of the most familiar of all tests is that carried on for the purpose of ascertaining the resistance of a conductor. Though it would seem as if this included the general scope of all tests of this character, yet other tests of equal importance in an engineering sense must be made of the very opposite of good conductors, namely, insulators. Thus, tests of resistance might be generally classified as measurements of very low resistances, very high resistances and of resistances which occupy a middle place between these two. To illustrate—resistances of 0.01 of an ohm, of 1000 ohms and of 1,000,000 ohms, repre-

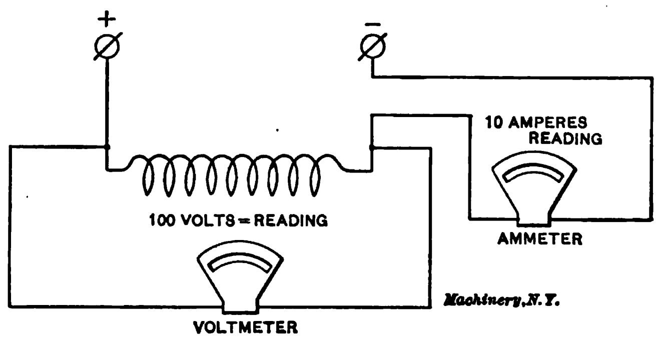

Fig. 17. Obtaining the Resistance in a Circuit

sent a great difference in value, and different methods must be used for each. A few of these methods will be considered under the heads of: 1. Drop of Potential Method; 2. Method of Substitution; 3. Wheatstone Bridge Method.

Drop of Potential Method

There is no reason to believe that a simpler method than the drop of potential method can be presented in developing devices of resistance measurements. It is based upon the proposition contained in one form of Ohm's law that the pressure which is necessary in a circuit, to send a given current through a given resistance, is equal to the product of this current by the resistance. In other words, if the problem is presented to find the resistance of a circuit (see Fig. 17) whose lost pressure or "drop" equals 100 volts when carrying a current of 10 amperes, the answer can be readily given on the above basis. A loss of 100 volts, or whatever it may be, is caused by a cer-

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tain current passing through a definite resistance. The problem in arithmetic form then becomes, 100 = 10 times what value? It is quite evident that the value to be found is 10. The drop in pressure between the ends of the circuit being 100, and the current being 10 amperes, the resistance must be 10 ohms. The drop of potential method therefore, consists in a measurement with an instrument called the voltmeter (instrument for measuring electromotive force or electric pressure in volts) of the drop of pressure between the ends of a circuit through which current is passing. The next step is the measurement of the current itself with an ammeter (instrument for measuring current in amperes). Dividing the volts by the amperes will give the ohms as indicated. The test may be made in other ways, which merely represent modifications of this idea without any real change in the method. For instance, if the resistance of the circuit

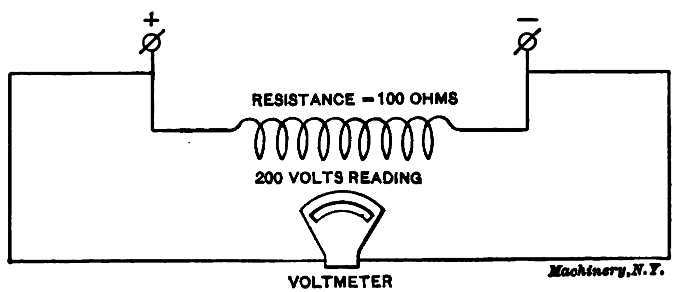

Fig. 18. Obtaining the Strength of Current in a Circuit with a Voltmeter and a Known Resistance

is known, it is a simple matter to find the number of amperes passing through, by ascertaining the drop in exactly the same manner. The drop in volts divided by the ohms will give the amperes. On the other hand, the idea may be still further developed for the purpose of discovering the volts consumed by the circuit. In this case the resistance, which is known, is multiplied by the current which is measured. The product will give the volts lost or "drop" of the circuit. The general idea thus presented covers a means of obtaining the resistance if the amperes and volts are known; the volts, if the amperes and ohms are known; and finally the amperes, if the volts and ohms are known. It is legitimate to include all of these tests under the one general category. Rules and examples for the application of these methods are given in the following.

DROP OF POTENTIAL METHOD

To get ohms...........	Measure the drop and measure the amperes................	Divide E by C
To get amperes........	Ohms known; measure the drop.,...........	Divide E by R
To get volts...........	Ohms known; measure the amperes.........................	Multiply C by R

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Examples of the Drop Method

A voltmeter (see Fig. 18) shows a drop of 200 volts between the terminals of a circuit carrying a certain current. The resistance is known to be 100 ohms; what is the current in the circuit? Dividing 200 by 100 gives a current of 2 amperes.

An ammeter shows a current of 10 amperes in a circuit having a resistance of 50 ohms (see Fig. 19); what is the pressure or "drop"? Multiplying 10 by 50 gives a voltage of 500.

How many ohms resistance has an incandescent lamp hot, whose terminal pressure is 120 volts, and which takes a current of 0.4 of an ampere. Dividing 120 by 0.4 gives a resistance of 300 ohms.

It is possible to use an ammeter as a voltmeter or a voltmeter as an ammeter by securing a definite length of copper wire of sufficient size to cause a slight drop when the current passes and yet not dissipate too much energy. For instance, 1000 feet of No. 10 B. & S. gage copper wire would give a resistance of 1 ohm. If a piece of wire is obtained whose resistance is known, and this wire is placed in series with a motor, the voltmeter, giving the drop across its terminals, will

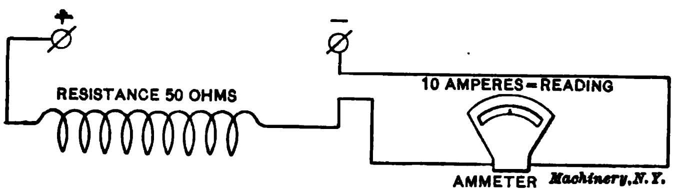

Fig. 19. Obtaining the Voltage of a Circuit with an Ammeter and a Known Resistance

be the means of measuring the current. If the voltmeter reads 2 volts, and the resistance of the wire is 0.1 of an ohm, then 2 divided by 0.1 equals 20 amperes. If instead of a voltmeter an ammeter is used, the test for volts can be made, but the resistance must be greatly increased and must be disconnected from the motor if accurate measurement of the pressure is to be made. If the line pressure is 220 volts, it may be sent through a resistance of 100 ohms, and the reading of an ammeter in series will complete the test. Under these conditions 2.2 amperes would be indicated, the product of this current and 100 ohms giving the line pressure, 220 volts.

Measuring High Pressures

For the measurement of pressures like 1000, 5000 or 10,000 volts, the following plan is practicable: Either 10, 50 or 100 lamps are connected in series. If about 1000 volts are to be measured, about 10 lamps will do. The total pressure is then sent into this series as shown in Fig. 20. A voltmeter is used for the purpose of taking the drop between the terminals of every lamp. The total is found when all results are added together. For instance, if the voltmeter indicated as follows: First lamp, 90 volts; second lamp, 95 volts; third lamp, 100 volts; fourth lamp, 110 volts; fifth lamp, 105 volts; sixth lamp, 98 volts; seventh lamp, 99 volts; eighth lamp, 102 volts; ninth

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lamp, 85 volts; tenth lamp, 87 volts; then the total equals the sum of 90 + 95 + 100 + 110 + 105 + 98 + 99 + 102 + 85 + 87 volts, or 971 volts in all. This is an early method of measuring the high pressures of alternating currents before high-reading voltmeters were made.

Method of Substitution

Measuring resistance by the method of substitution is really a comparative method. If a certain known resistance will cause an indicating instrument to show a deflection of 100 divisions, and then, when another resistance is put in its place, the deflection falls to one-half or 50 divisions, it is evident that the resistance must be twice as great. The reduced deflection means less current or more resistance. If the conditions are otherwise the same, the drop in the reading of the indicating instrument to one half proves the presence of twice the resistance. Ohm's law, as stated, that the current is directly proportional to the electromotive force, and inversely proportional to the resistance means, when applied to this case, that if the electromotive

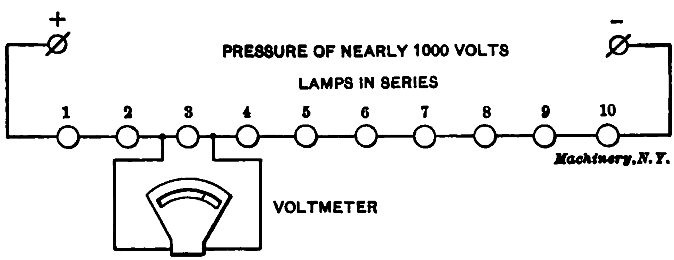

Fig. 20. A Method for the Measurement of High Voltage

force has not changed, but the current is one-half as shown by the deflection, the resistance is twice as great. To illustrate this idea, an instrument used for indicating electric currents, and called a galvanometer, may be connected to a cell of battery and a known resistance of say 100 ohms, as shown in Fig. 21. If under these conditions, the galvanometer gives a reading of 20 divisions, the record will read, 100 ohms, 20 divisions. Assume that the 100 ohms resistance is removed, and an unknown resistance, such as a lamp, is put in its place. Suppose the galvanometer now shows a deflection of only 5 divisions, as in Fig. 22. The conclusions to be drawn are as follows: If 100 ohms gives a reading of 20 divisions and an unknown resistance gives a reading of 5 divisions, then the unknown resistance must be greater. Its resistance is so much greater that it reduces the current down from that value which gives a 20 division reading, to a value so much less that only a 5 division reading is possible. In other words, the reading has been reduced in the galvanometer from 20 to 5 divisions because the current passing through it has been reduced. The reduction is due to the new unknown resistance substituted for the known resistance. If the resistance in the first case was 100 ohms, it must in the second case in conjunction with that of the galvanometer, be

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four times as great as the original resistance. If the galvanometer resistance equals 100 ohms, then it is evident that 100 + 100 = 200 ohms causes a deflection of 20 divisions. It also shows that 100 + an unknown resistance gives a deflection of 5 divisions. The question that naturally arises is "What is the unknown resistance?" As previously stated, it must have taken four times the resistance to reduce

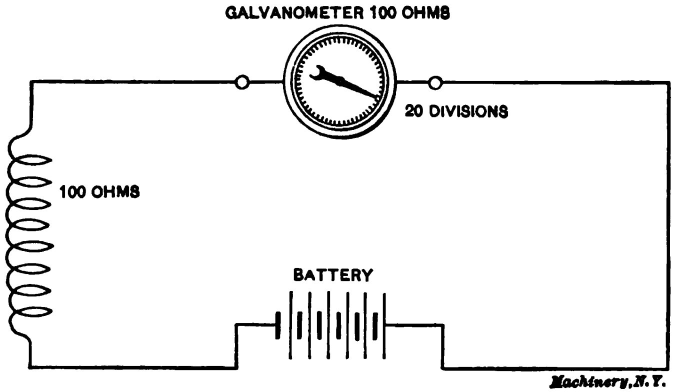

Fig. 21. Galvanometer used for Measuring Resistances by the Method of Substitution

the reading from 20 to 5 divisions. This being the case, the 200 ohms in the first instance must have been increased to 800 by the addition of the unknown resistance. If the galvanometer resistance, however, is 100 ohms, then the unknown resistance must be equal to 700 ohms. Thus, the method of substitution as outlined, calls for a knowledge of the resistance of the galvanometer, or indicating instrument.

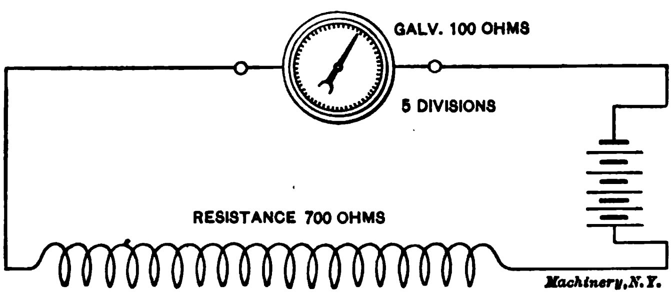

Fig. 22. Reading of Galvanometer when Unknown Resistance is Substituted

It also calls for a knowledge of the value of the first resistance interposed. With these facts known, it is evident that any reasonable resistance may be substituted for the first, and if the deflection is taken, the resistance is readily calculated.

Measuring the Resistance of Insulation

The resistance of insulation is enormous compared with that of conductors. An insulator, so-called, is not an absolute non-conductor,

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but a very poor one. The idea is relative. A pressure of 1000 volts, applied to a resistance of 1000 ohms would mean a current of 1 ampere. A pressure of 1000 volts applied to a resistance of 1,000,000 ohms, would mean a current of 1/1000 of an ampere. If the pressure is lower, the current is correspondingly less. A telegraph line is supported on insulators. Though made of glass, these insulators permit current to leak from the line to the ground. Not one support alone, of course, is responsible for the entire leakage. An infinitesimal current from one, multiplied by the number of insulating supports, would give the total current. If in the above case, the one thousandth of an ampere was multiplied by 10,000, the total would equal 10 amperes. This is not entirely an imaginary case for the reason that 10,000 insulators, at the rate of 25 to the mile, would only equal 400 miles between stations. The leakage per insulator might be less than that stated, but whatever it was, it would be multiplied by 10,000 on a 400-

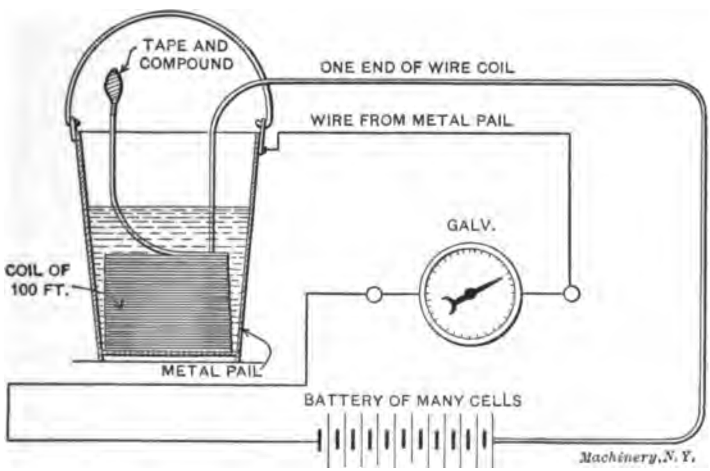

Fig. 23. Measuring the Insulation Resistance of Rubber Covered Wire

mile line. Not only is it necessary to know the relative merits of insulators for line service in order that line leakage may be reduced to its lowest value for telegraphic and other lines, but the insulation of power-carrying wires must be known as well.

The following is an outline of the method of measuring insulation resistance, by the principle of the substitution of one resistance for another: The requirements are a metal pail, a sensitive high resistance galvanometer, and a carefully tested high resistance. (See Fig. 23.) With these, the value of the resistance of high-grade insulation, reaching into the millions of ohms, can be found. The insulator, or insulated wire, is so placed in the water that the current passes through from the metal pail and the conducting solution into the insulation, and then out via the wire. If a coil of insulated wire is tested, consisting of say 100 feet of rubber covered wire, then one end of the wire is carefully coated with tape and an insulating compound.

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The other end leads out, as does also a separate wire connected to the metal pail. The coil is laid in the pail and covered with water slightly tinctured with sulphuric acid to lower the resistance of the water. The preliminary test is then made with a resistance of 10,000 ohms, which will cause a deflection of 50 divisions in the galvanometer. Supposing the galvanometer to possess a resistance of 10,000 ohms, the first galvanometer deflection is due to 20,000 ohms in all. Removing the 10,000 ohms resistance from the circuit, the insulated coil situated as described in the water, is substituted in its place. If the deflection in this case is only one division, then it is clear that 50 times the resistance is in place now. In other words, where 20,000 ohms gave 50 divisions, it has taken 1,000,000 ohms to cut this down to 1 division. Of the one million ohms, 10,000 are due to the galvanometer resistance. The balance of 990,000 is the resistance of the hundred feet of insulated wire in the metal pail. As a single foot of wire would show a resistance higher than this, in fact 100 times as great, it may be

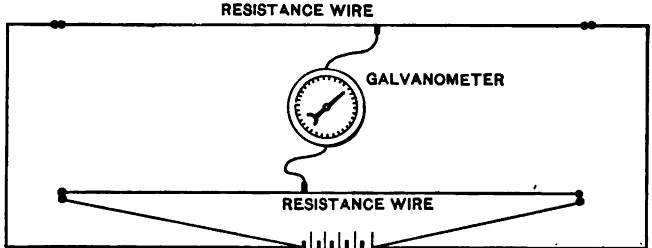

Fig. 24. Illustrating the Fundamental Principle of the Wheatstone Bridge

stated that according to the test, 1 foot of this wire has an insulation resistance of 100 times 990,000 ohms or 99,000,000 ohms, commonly called 99 megohms.

The Wheatstone Bridge

The Wheatstone bridge is an almost historic instrument, and is perhaps the most extraordinary device in the world. By its means, resistances can be measured with accuracy which express a range of difference equal to the ratio of one-thousandth to a million. This ratio numerically is that of one to a billion and cannot be equaled by any simple device in existence. It is as if a pair of scales could weigh with equal accuracy, one one-thousandth of an ounce and a million ounces. This extraordinary device is used for the purpose of measuring all kinds of resistances, high and low. The value of insulation resistances are discovered by the method just described; but for general resistance measurements, the Wheatstone bridge is universally used. It practically consists of a loop of wire so constructed that a galvanometer whose terminals rest on each wire of the loop, respectively, will indicate the difference in drop between one part of the wire to which it is attached, and the part of the other wire to which it is similarly joined. For instance, if two parallel wires of a certain

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resistance carry a certain current, it is easy to realize that the terminals of a galvanometer will find a place on each wire respectively where the drop will be equal. (See Fig. 24.) Under these conditions no current could possibly flow into the galvanometer. If the upper or lower terminal of the galvanometer is shifted a trifle either way, it will take a potential higher or lower than that of the other wire, and a current will consequently flow through the instrument. When the two points spoken of are found, however, the galvanometer remains unaffected. This condition is expressed by saying that the *A* arm (see Fig. 25) is to the *B* arm as the *C* arm is to the *D* arm. By this is meant that the resistance of *A*, *B*, *C* and *D* bear a certain relationship to each other. If they are given such values as 10, 20, 40 and 80 ohms, then 10 is to 20 as 40 is to 80. The fact that *A* is to *B* as *C* is to *D*, is only true, of course, when the galvanometer terminals reach these particular points where the "drops" of the two wires are alike.

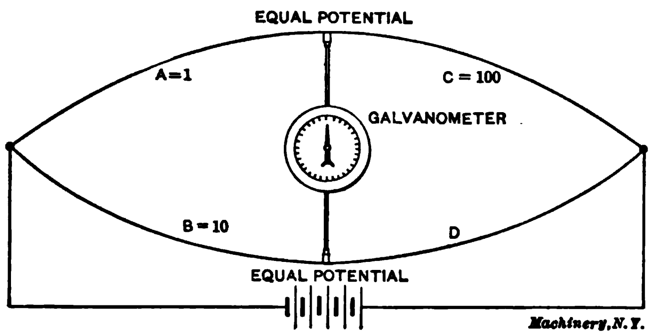

Fig. 25. Diagrammatical Representation of the Wheatstone Bridge

Now, if the two wires are joined at each end to form a loop with the galvanometer between and a battery supplying the joined ends with current, as in Fig. 25, then the conventional Wheatstone bridge appears ready for service. In practice, the *A* and *B* arms express the ratio of 1 : 10 or 1 : 100 or 1 : 1000. The *C* arm is adjustable, so as to develop a balance between itself and the resistance to be measured. Supposing the *A* and *B* arms are set at the ratio of 1 : 100, then if the unknown resistance is inserted, and the *C* arm adjusted by manipulating the resistance it represents until the galvanometer does not show any deflection, the bridge is said to be balanced. If the balance was only possible when the *C* arm was made equal to 100 ohms, then the *D* or unknown resistance must be equal to 10,000 ohms. The method is simple enough if the necessary ratio of $A : B = C : D$ is remembered. If, for example $A = 1$, $B = 10$, $C = 100$, then $1 : 10 = 100 : D$. According to these figures $D = 1000$ ohms. If the bridge is constructed with many *A* and *B* ratios, the range of measurement is thereby greatly increased.

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CHAPTER III

BATTERIES

A battery as understood by the scientific world of to-day, is a device by means of which chemical energy is directly transformed into electrical energy. Were it possible to burn coal and obtain electricity without the aid of an engine or dynamo, the process would be very similar to that taking place in a battery. Here, the fuel is generally a metal and an acid, and from these two electricity is produced as a full equivalent of the transformation which takes place.

The Voltaic Pile

The Voltaic pile, Fig. 26, consists of a disk of zinc and copper resting together, then a disk of blotting paper slightly tinctured with acid, then two more disks, respectively of zinc and copper, then blot-

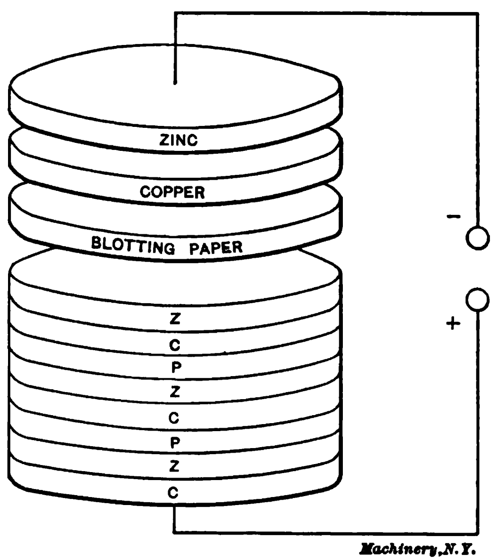

Fig. 26. The Voltaic Pile

ting paper, etc. This arrangement of metal disks is historic and proved a source of the greatest interest to the rising world of experimenters of over a century ago. As it represents the earliest type of battery of which any records exist, and as from it arose the multitude of diverse forms, including both the dry and the wet battery, with its many modifications, it is evident that an examination of the principles it embodies will prove interesting and instructive.

What is generally called a simple voltaic cell, Fig. 27, consists of a

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jar containing a diluted solution of sulphuric acid and two elements. These elements are respectively plates of zinc and copper. On bringing together two wires attached to these plates, a current of electricity will flow.

Action on the Plates

The zinc plate will gradually dissolve in the solution, and while undergoing this process, it develops electricity. The copper plate seems to serve a different purpose. It is not affected to any extent by the chemical process taking place, but simply serves as a means of transmitting the electricity. For this reason the pole of the passive plate is called the positive and the pole of the plate acted upon is called the negative pole. In reality, the plates deserve opposite names, because the plate producing the electricity is the positive plate, although the

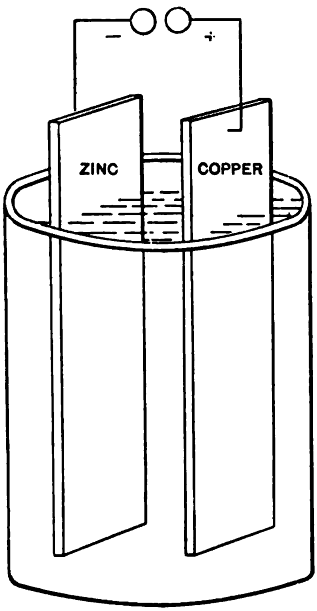

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Fig 27. Simple Voltaic Battery

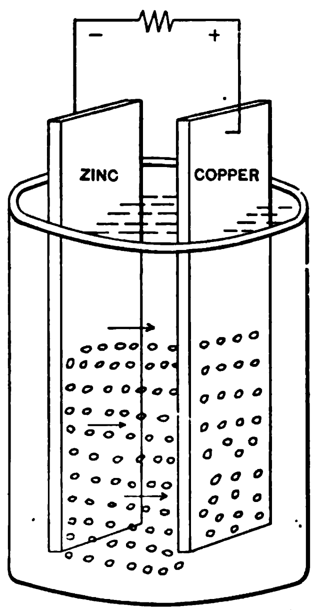

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Fig. 28. Principle of Process of Polarisation

negative pole, and that to which the current is transmitted, is, more accurately speaking, the negative plate, though the positive pole.

The voltaic pile composed of alternate disks of copper and zinc, is a simple dry battery in which the dampened paper, slightly acidulated, acts upon the zinc and in producing chemical action develops electricity.

What is generally understood as chemical action, is a union taking place between dissimilar substances to form a new product. This is familiar to the layman as well as the chemist, but the fact that is not so evident is that whenever chemical action takes place, electricity

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is developed. In other words, that which is called a battery, is simply a device in which chemical action is directly transformed into electricity.

Polarization

A simple voltaic cell will not run well very long. It will gradually fail and its power diminish to a point so low that little or no current is perceptible. A battery of this kind consists of two plates, as stated before—one of zinc and one of copper. These plates rest in an acid solution which attacks the zinc plate. If a jar of this character, containing such elements, is held up to the light the effervescence in the neighborhood of the zinc will be easily perceived. This is due to the sulphuric acid combining with the zinc, thus producing zinc sulphate and hydrogen gas. The solution will also begin to heat up, and a stream of hydrogen will pass across the liquid from the zinc plate, as shown in Fig. 28, and cluster around the copper plate. Hydrogen is one of the lightest and consequently the most buoyant of gases, yet it will not rise from the zinc to the surface directly, but instead moves horizontally to the copper plate. The clustering of these hydrogen bubbles around the copper plate has the effect of weakening the current to such an extent that it is merely necessary for enough of them to gather to completely destroy the value of the cell as a producer of electricity. When this condition has been reached the battery is said to be polarized. Polarization, therefore, is a condition in a cell brought about by chemical and electrical action through which hydrogen gas is deposited upon the copper plate and interferes with or prevents the action of the cell.

The gas on the copper plate is carried over by the current. The action is called electrolytic, by which is meant that an electric current has the power of carrying over from pole to pole certain constituents that it finds there. In the case of a simple electric cell, the current travels from the zinc through the liquid to the copper plate. The action therefore is exactly similar to electroplating, only instead of zinc being carried over, hydrogen is transmitted. The copper plate is therefore plated with hydrogen gas, which has two effects upon the action of the cell as an electrical generator. First, the hydrogen acts as a non-conductor, and therefore prevents the electricity from passing into the copper plate; second, the hydrogen has the effect of tending to develop a current in the opposite direction in conjunction with other elements of the cell. These two injurious influences cause the simple voltaic cell to cease its action after a short time has passed.

The ebullition due to intense chemical action will not diminish even though no current flows outside. The process by which current can develop and be used under these circumstances is seriously interfered with, and in consequence methods are employed to destroy the effect of polarization in a cell.

Methods of Depolarization

The methods of depolarization may be classified under three distinct headings:

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First—Depolarization by mechanical means.

Second—Depolarization by chemical means.

Third—Depolarization by electro-chemical means.

There are no primary batteries in use which do not employ one of these three methods to accomplish the purpose in view, namely, the annihilation of polarization.

Mechanical Method

The mechanical method is the simplest method of all to grasp, as it is quite evident that if the liquid in the battery is vigorously stirred the hydrogen bubbles will be dislodged and the gas thus freed will pass to the surface and disappear. The liquid can be kept flowing, which will accomplish the same purpose.

In many early batteries, air was blown through the liquid and the hydrogen thereby removed. One of the most interesting cases of the

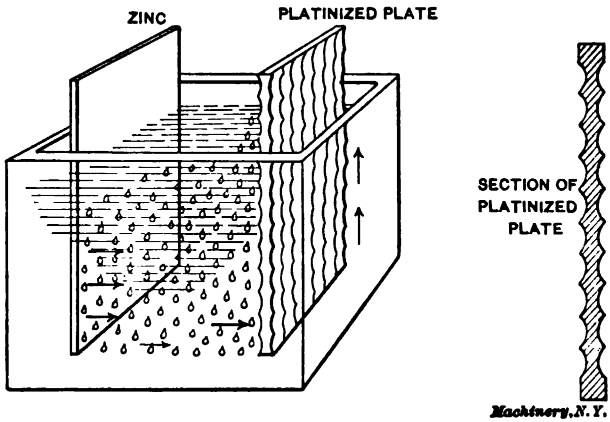

Fig. 29. The Smee Battery with Corrugated Platinized Plate for Preventing Polarization

application of mechanical means is found in the Smee battery. This is a cell greatly in vogue in the past for electroplating necessitating the use of powerful electric currents. The negative plate of this cell (see Fig. 29) was constructed so that it presented a surface of platinum to the liquid, but not a smooth surface. It was rough and prickly, and the general appearance of it, as shown, indicates the difficulty with which hydrogen bubbles could lodge and adhere to the surface. In a cell of this kind the hydrogen passes freely over from the zinc to the platinized copper plate with the result that a continuous stream of hydrogen gas ascends from the negative plate to the surface of the liquid. It is possible, therefore, to sum up the mechanical method of depolarization in the following manner:

First—Depolarization by agitating the liquid.

Second—Depolarization by air blown through.

Third—Depolarization by using rough plates.

Means are employed nowadays which insure to a large extent the continued action of the battery in cases where such action is expected.

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Open and Closed Circuit Batteries

Polarization has been the means of dividing batteries up into two general classes. They are called:

1. Open circuit batteries.
2. Closed circuit batteries.

In the open circuit batteries it is the intention of the manufacturers to produce a cell which can be used for occasional work without attention. The so-called dry cell, Fig. 30, is a well-known type of this kind. These cells polarize rapidly, but only when kept in continual use. On the other hand, if placed on a shelf or in an out-of-the-way place they require no attention and may be thrown away at the end of a year or more of intermittent use. Such cells are distinctly open circuit cells, that is to say, they are on open circuit most of the time. If kept on a closed circuit for any longer period, polarization will set in and the cells rapidly become useless unless allowed to recuperate. An open circuit cell is not provided with means for rapidly depolarizing its negative plate. It has not the proper chemicals within to destroy the hydrogen gas rapidly enough to permit an uninterrupted and undiminished flow of current.

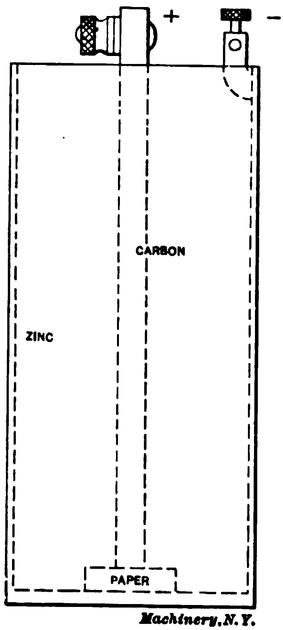

Fig. 30. Open Circuit Dry Battery, Showing Zinc Envelope Containing Chemicals and Carbon Plate

In the closed circuit batteries the opposite idea in a sense prevails. The manufacturers of these want to provide a source of electricity which can be permitted to flow for long periods of time without considerable diminution of strength. One of the most familiar batteries of this type is the old gravity battery so much employed on telegraphic lines. It may be connected up to a circuit and will give current for weeks and months at a time. In fact, it is so distinct a type of the closed circuit battery that, whereas the dry cell as an open circuit battery must not be on closed circuit for more than a few minutes at the most at a time, the gravity battery must be kept on closed circuit and must not be left on an open circuit for more than a short time during its use.

In a dry cell depolarization is slow, but the cell will not eat itself up rapidly when not in use. In the gravity cell depolarization is rapid but the production of current is limited, though continuous, and in this respect the open and closed circuit batteries represent fundamental ideas based upon the method of producing depolarization rapidly and continuously or slowly and occasionally.

The greatest activity in battery invention took place in France thirty

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or forty years ago. In one of the principal squares of Paris, electric lamps were set up, and the current supplied to them was obtained from powerful batteries. One of the famous equipments installed was called the cascade battery, Fig. 31, which consisted of tier upon tier of cells arranged on a pyramidal series of platforms. The liquid was pumped from a receiving tank at the bottom to the upper cells and from them it descended through a series of pipes to the tank below, thus passing through all cells in succession. The liquid in this system was in a constant state of motion and thus a mechanical method of depolarization was obtained.

In some cases part of the current was diverted through a motor, which, by running a fan, blew air through the liquid of the cells. In other cases the liquid was stirred and this effectually dislodged the hydrogen bubbles. All the methods outlined produced an agitation in

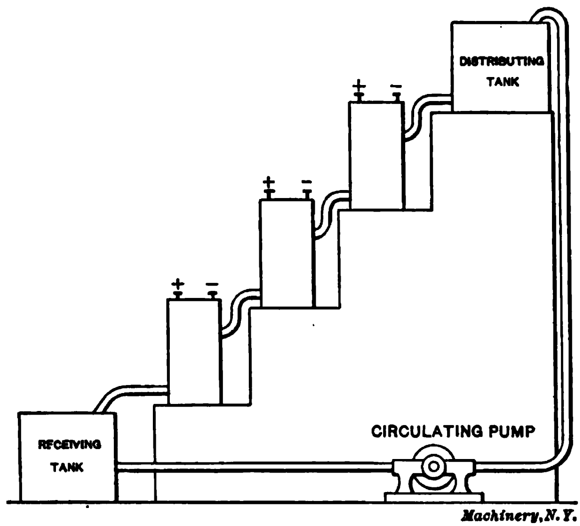

Fig. 31. Batteries with Circulating Fluid

the liquid which caused depolarization; but by far the most important of the three classified means of producing depolarization is the chemical method.

Chemical Method of Depolarization

Hydrogen is a gas possessing a great affinity for oxygen. The use of a chemical mixed with the solution, the said chemical possessing a great deal of oxygen, would be effective in combining with the hydrogen, and thus free the cell from the injurious effects of polarization. A chemical in common use for this purpose is bichromate of potash. This crystal possesses a great deal of oxygen bound up with the other elements which constitute it. In consequence of this, when a diluted solution of sulphuric acid dissolves crystals of bichromate of potash, the new solution possesses hydrogen-absorbing properties which are

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used directly in the construction of what it called a bichromate of potash battery.

When the acid solution attacks the zinc, hydrogen gas in very small bubbles is released and carried over towards the other plate, consisting in this case of carbon. It is rapidly taken up by the bichromate in solution, the oxygen combining with the hydrogen and thus permitting the cell to continue to develop a strong current. If the chemical activity between the zinc and the acid is too intense, gas will be released more rapidly than the oxygen in the bichromate can absorb it. In this case, a gradual polarization would ensue and the battery weaken. A battery will polarize, therefore, in spite of the chemical method of depolarization if sufficient depolarizing material is not employed.

In the so-called open circuit cell depolarization is not rapidly carried on. The depolarizing material, such as that used in dry cells, is dioxide of manganese, which simply represents a chemical containing enough oxygen to slowly absorb or combine with hydrogen. When a dry cell is in use, the salammoniac in contact with the zinc shell of the battery releases hydrogen gas. This gas attempts to pass through the cell to the carbon pole. Before reaching it, however, the dioxide must be traversed. Here the hydrogen is assimilated and the carbon freed from the effects of polarization. The dioxide cannot absorb the hydrogen very rapidly. This is the reason why a dry cell will quickly polarize if used continuously. Were it constructed, however, with a great deal of the depolarizing material arranged around and in contact with the negative plate, it is very likely that the cell would be able to operate continuously while giving a comparatively powerful current; but this would mean a bulky cell and an expensive one as well. The salammoniac solution which acts upon the zinc merely dampens the pulp or packing which is employed in contact with the zinc. A dry cell is therefore a damp cell inside though sealed on top to prevent evaporation.

A cell which polarizes quickly is merely a cell whose constituents combine with the hydrogen slowly. On the other hand, a cell which can remain on a closed circuit a long time is one which absorbs the hydrogen quickly. This distinction is very important and shows that the classification on this basis is the only practical one to make with reference to the utility of the cell.

Mixed Types of Cells

Cells have been constructed which possess the qualifications that entitle them to be used for both intermittent and constant service. A cell of this description also makes use of bichromate of potash and a diluted solution of sulphuric acid. As a general rule the water is acidulated until a 10 per cent solution is made—ten parts water and one part acid. In the simple form of the bichromate battery it is the custom to saturate the solution with bichromate crystals. To accomplish this, warm water is employed in which enough crystals are dissolved, and then the acid is added.

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A rule which must never be broken is that the acid must be added to the water, *never the water to the acid.* If this rule is not observed serious injury may result to the experimenter. The jar will crack through the intense heat and the acid will spatter around. If it gets into the eyes or on the hands or clothes an alkaline solution must be applied at once. Ammonia or soap and water are effective antidotes.

Action on the Zinc

Before considering other types of batteries, a curious phenomenon must be observed in connection with the zinc. If a rod of zinc is used as one element and a rod of carbon or copper as the other, then when both are inserted into a diluted solution of sulphuric acid, effervescence immediately begins in the neighborhood of the zinc. The acid attacks the zinc in the following manner:

Sulphuric acid + zinc = zinc sulphate + hydrogen.

$$H_2SO_4 + Zn = ZnSO_4 + H_2$$

This simply means that the acid and zinc combine forming zinc sulphate and thus release the hydrogen from the acid.

In an ideal cell, the zinc should not be consumed unless the battery is in use. And it may be furthermore stated that *pure zinc* will not eat away in a diluted sulphuric acid solution. The question then naturally arises, "Why does the zinc eat away at all?" To answer this question correctly, it is necessary to understand that commercial zinc is impure, and in consequence of this, the impurities with which it is permeated, such as particles of iron and carbon, etc., form small voltaic cells with the zinc in which they are embedded. This causes intense chemical action, and the zinc wastes away, whether the cell is in use or not.

Amalgamating the Zinc

To remedy the serious and otherwise insurmountable defect mentioned in the previous paragraph, a coating of mercury is applied to the zinc rod. First the zinc is dipped in a solution of diluted sulphuric acid, and then, after it is thoroughly clean, the mercury is poured over it, or it is dipped into a dish or bottle containing mercury. If a rag is used the amalgamating process is carried on more successfully. The action of the mercury is as follows: It dissolves the zinc, leaving the impurities behind, and thereby presents to the action of the acid a coating of pure zinc mixed with mercury. The mercury is perfectly neutral, and in consequence a well amalgamated piece of zinc may be allowed to remain in an acid solution for many days without any waste of the zinc taking place. A bichromate of potash battery supplied with well amalgamated zincs, will use up the zinc only when the battery is in use. If there are impurities in the mercury or acid, a slow action will take place, and the zinc, if allowed to remain in the solution, will disappear. This difficulty has been met in at least one instance by the invention of a means of automatically amalgamating the zinc.

A cell called the Fuller mercury bichromate employs the follow-

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ing method for automatically amalgamating the zinc. Instead of a zinc rod, a cone of zinc is employed. This rests on the bottom of a porous jar, Fig. 32, and into the jar a tablespoonful of mercury is poured. A diluted solution of sulphuric acid is then poured into this jar. An outer glass jar holds a bichromate of potash solution, and in this solution either one or more carbon rods are suspended. If the acid solution acts upon the zinc, there is always mercury there to heavily reamalgamate it. This is of course an automatic action, the mercury climbing up the cone of zinc, and thereby preserving its integrity until the battery is on a closed circuit. The hydrogen which is released passes through the walls of the porous jar, and meets the bichromate solution which combines with it.

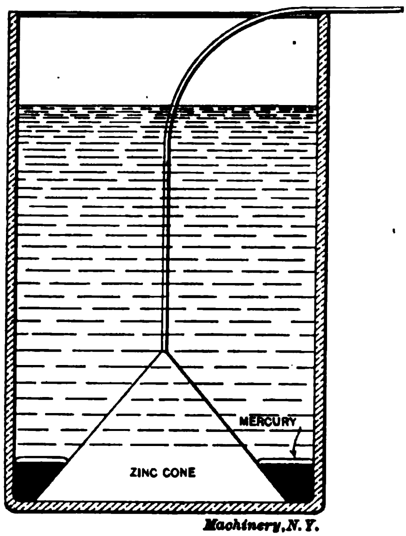

Fig. 32. Automatic Amalgamation

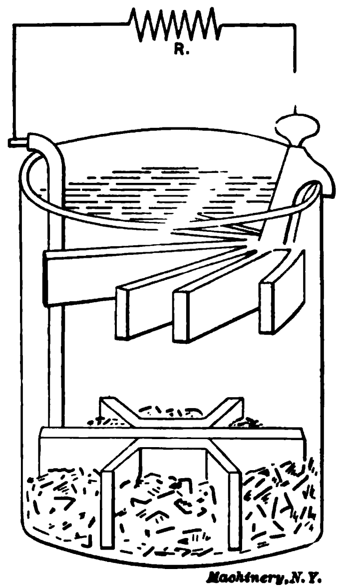

Fig. 33. Closed Circuit Gravity Battery

A cell of this description may be used for continuous work, and will under these circumstances deliver a strong current. On the other hand, if used only occasionally, it will act as an excellent open circuit battery, because no waste of material can take place when it is not in use. Evaporation will occur, and the acid may lose its strength in the course of time, but cells of this character are good for several years of service on open circuit and are exceptionally reliable for closed circuit work as well.

Recapitulation

In relation to prevention of polarization, two methods have been considered: the mechanical and the chemical. The purpose of amalgamation is to prevent "local action." This is the term employed to describe the injurious effect of the presence of impurities in zinc. It

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has been attempted by manufacturers to cast the zinc with mercury, and thus offer on the open market a zinc presumably free from local action when in use. The effort was unsuccessful, because the zinc did not retain enough mercury to make such an alloy equivalent to a thorough amalgamation, neither has it been found possible, except in rare cases, to substitute any other metal for zinc in a battery. Thomas A. Edison has succeeded to some extent, but the fact remains, that to-day, both dry and wet cells employ zinc as an indispensable element, and in addition a positive plate of carbon or copper.

The Electro-chemical Method of Depolarization

The third method of reducing or removing the hydrogen from a battery may be found in the first popular type of cell in practical use This cell, greatly used to-day, and exclusively employed in this country in the past for telegraph lines is called the gravity battery. The name was given to it because the two solutions this battery holds when in normal action are separated from each other solely by gravitation. The two solutions are respectively sulphate of copper, which is in this case the under layer, and sulphate of zinc, the layer of solution resting on the first. Their specific gravities prevent them from mixing as long as they remain undisturbed. In this cell a crowfoot of zinc is suspended above in the sulphate of zinc solution. Below is found a cross of copper surrounded by a solution of sulphate of copper, and with copper heaped around it. (See Fig. 33.)

The zinc is acted upon by the solution around it and hydrogen gas is produced which seeks to travel downward to reach the copper cross below. (See Fig. 34.) Here it enters the sulphate of copper solution at the point where both meet. The sulphate of copper solution seizes hold of the hydrogen gas, but substitutes for it a particle of pure copper. The pure copper particle continues to travel toward the copper cross the same as if it were the hydrogen bubble. It follows the same route and finally attaches itself to the copper cross. This action, instead of interfering with the output of electricity from the cell, improves it. When the hydrogen gas meets the sulphate of copper solution the following exchange takes place:

Hydrogen + sulphate of copper = copper + sulphuric acid.

$$H_2 + CuSO_4 = Cu + H_2SO_4.$$

This means that when hydrogen gas and sulphate of copper combine, sulphuric acid is made and pure copper (Cu) is separated. In the electro-chemical method of depolarization the hydrogen gas is held, and the resulting copper sent on in its place over the same path to deposit itself, instead of the hydrogen, on the copper element. This, of course, results in an accumulation of pure copper on the copper element, the complete absence of polarization, and an absolutely continuous current of electricity of increasing instead of diminishing strength.

This brilliant idea of substituting a metal through the agency of electricity, in place of the hydrogen gas is originally due to Daniell, the

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inventor of the famous Daniell cell at one time accepted as a standard of electric potential, but subsequently converted into the now better known gravity battery. The Daniell cell, like the gravity battery, makes use of the same elements and naturally operates along the same general lines.

Zinc as Fuel

Power is produced in a cell by chemical action taking place between the zinc and acid. As zinc is employed in the great majority of batteries, and as this metal is consumed during the operation of the cell, it must be regarded as the fuel through which the transformation of chemical energy into electrical energy is effected. If during the operation of a cell, the liquid becomes very warm, it is a sign that the processes are not taking place properly, and the energy which should be transformed into electricity is being dissipated as heat.

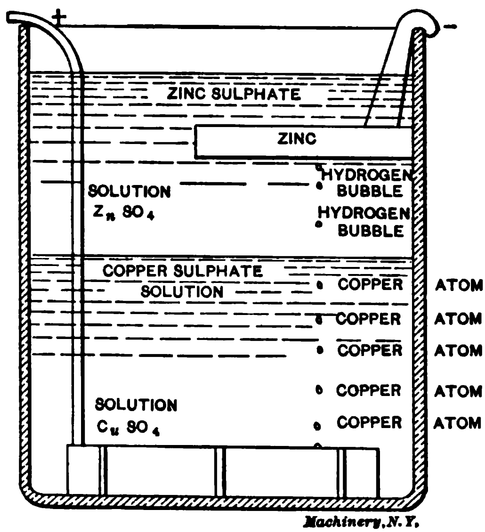

Fig. 34. Illustrating the Action of the Gravity Battery

If zinc is to be regarded as fuel, the battery utilizing it cannot be considered as differing essentially from a steam boiler, whose power in the form of steam under pressure is the result of the chemical processes taking place between the coal and the oxygen in the air. In the general run of steam plants it takes from 4.5 to 6 pounds of coal to give 1 horsepower for one hour. In a battery it takes from 1 to 2 pounds of zinc to give 1 horsepower-hour. The reason why the amount of zinc per horsepower-hour differs so much is because the number of volts produced by different cells differ. For instance, it is well known that the number of volts produced by a zinc and copper cell are about 1, whereas the number of volts produced by a zinc-carbon cell is about 2. In other words, the elements composing a cell give a number of volts depending upon the character of the elements em-

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ployed and the nature of the solution. If this is true, then it must be understood that the amount of zinc consumed to produce a current of a given strength is always the same. The exact amount of zinc consumed to give a current of 1 ampere for one hour is 1.2133 gram. If these figures are turned into the English system, it will be found that the following results are obtained:

Volts of Cell.	Horsepower-hours.	Weight of Zinc.
1	1	2 pounds
1.5	1	1.33 pounds
1.75	1	1.14 pounds
2.00	1	1.00 pounds
2.5	1	0.80 pounds

To test a battery it is necessary to weigh the zinc plate before and after it has developed a given amount of current for a specified time. If there are marked differences between the figures obtained, and those given in the table, local action will be sufficient to account for them. Comparing the cost of electricity obtained from batteries with that obtained from electric light plants, the figures in the following will indicate the impossibility of the former at present competing with the latter. The question is essentially a commercial one, in which the contrasting figures show the costliness of electricity obtained by chemical action in batteries.

Cost of Electricity from Bichromate Batteries

A solution of sulphuric acid and bichromate of potash of the following proportions, costs about 35 cents a gallon: 1 pint water dissolving 3 ounces bichromate of potash; add 2 ounces sulphuric acid.

The cost of the zinc would be about 15 cents a pound, well amalgamated with mercury. On this basis, estimating that one pound of zinc will require one gallon of solution, it is easy to see that the generation of 1 horsepower-hour would involve the following expense with a 2-volt battery:

Zinc, 1 pound	15 cents
Solution, 1 gallon	35 cents
Total	50 cents

If these figures are compared with the cost of a horsepower-hour produced in an electric light station, where this power costs about 4.5 cents instead of 50, the ratio between the two is more than 10 to 1 in favor of the dynamo plant.

If batteries are used which give less than two volts, the cost rises until it is seen that any claims to do electric lighting, or to supply power from batteries, are necessarily absurd if the proposition is framed so as to indicate attempted competition with electric light and power plants.

The possibilities associated with the primary battery are very great from a theoretical standpoint. Many efforts have been made to obtain the energy from coal by electrical means without resorting to direct

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oxidation and combustion. If it were possible to reduce coal, so that while oxidizing it did not develop heat, but electricity, then a great problem would be solved. A well-equipped electric light plant is able to get the effect of about 14 pounds of coal out of every 100 pounds consumed. On this basis it is evident that more than six times the amount of power obtained is wasted through radiation, etc. An electrical method of reducing coal so as to transform its heat energy directly into electricity would represent a great saving of fuel and power. The general efficiency of a battery is high in comparison with an electric light plant. While a battery has over 70 per cent efficiency an electric light plant has only 14 per cent. But, as shown by the last

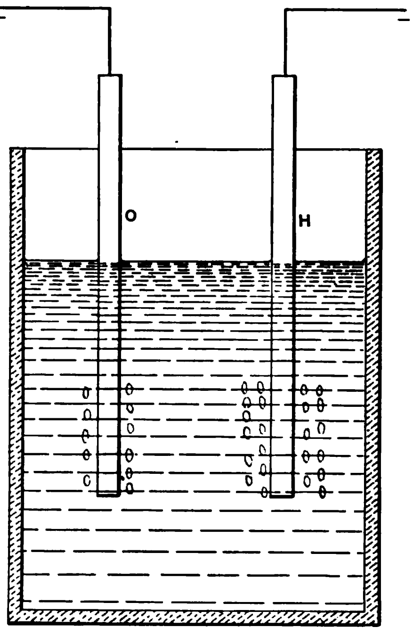

Fig. 35. Decomposition of Water

figures, the cost of the materials consumed is too great. This being the case, further progress in the field of battery construction is impeded.

Storage Batteries

Place the terminals of a battery of cells in acidulated water, as in Fig. 35, and note the bubbles which appear at the positive and negative poles. A close examination will reveal the fact that there are more bubbles at the negative than at the positive pole. The process taking place is this: The electricity in passing from pole to pole decomposes the water; the two gases composing water are oxygen and hydrogen and these gases collect at the two poles, the oxygen appearing at the positive, and the hydrogen at the negative pole. There is more hydro-

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gen than oxygen because water when decomposed yields twice as much hydrogen as oxygen.

If tubes, as shown in Fig. 36, are used to collect the gases at the two poles and these tubes partly dip into the water along with their platinum electrodes, then, when sufficient gas has been collected the following experiment can be tried: A galvanometer can be attached to the two electrodes, as in Fig. 37, and the effect of this connection noted. The needle of this instrument will, at the moment of connection, swing from a position of rest and indicate the passage of a strong current. The only explanation of this is by reference to the two gases and the electrodes. Here is a case of a current appearing, as if this combination of tubes, gases and electrodes with water represented the constituents of a battery. By sending a current into this combination of parts, gases are evolved. On bringing the terminals from the tubes

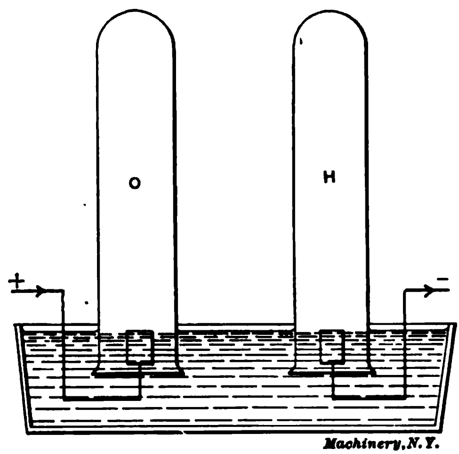

Fig. 36. Collecting Oxygen and Hydrogen in Tubes

together, after disconnecting the original source of electricity, a current is returned. This is, in many respects, the first type of storage battery evolved, and from this developed many of the types in common use to-day.

Gaston Plante may be considered the father of the modern storage battery. He tried the foregoing experiment and then decided to try metals other than platinum for his electrodes. The results obtained by the use of lead plates were so successful that little if any scientific progress has been made in this direction since his day. Lead electrodes when dipped in diluted sulphuric acid, and carrying an electric current, begin to oxidize. The plate connected to the positive pole becomes coated with a film of peroxide of lead, a reddish spongy development. The other plate, connected to the negative pole, is oxidized to a lesser degree. In this case the coating is one of dioxide of lead, a grayish and less spongy surface. (See Fig. 38.) When these

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oxidized surfaces appear, if the current is stopped and the electrodes connected to a meter or indicating instrument like a galvanometer, a powerful current will be noted.

The current will continue to flow from the plates for a while, and then it will cease. In order to develop a capacity within the plates for a continued supply of current, Plante found it necessary to "form" the plates. This is accomplished by sending a current in one direction, and then discharging the cell, and then in the other direction, and discharging the cell. By repeating this process and lengthening the intervals of charging the plates and discharging them, the so-called forming process is eventually completed. When the plates are formed, they are of a spongy texture, but their capacity is greatly in-

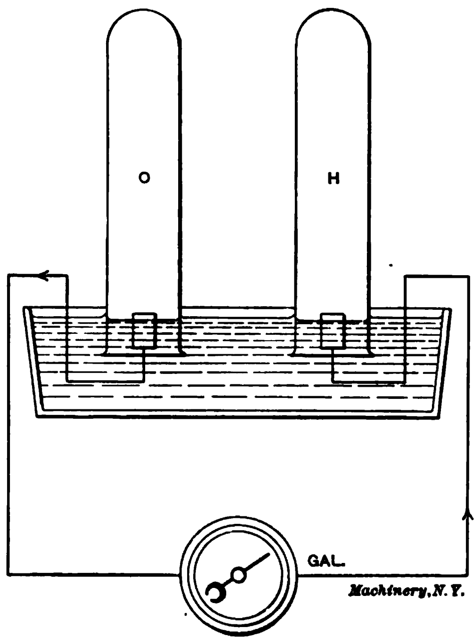

Fig. 37. The Simplest Type of Storage Battery

creased. The gases formerly seen at the beginning of the process do not appear. All of the energy applied in the form of electricity, in a theoretically perfect cell, is transformed into chemical energy within the porous and spongy plates of dioxide and peroxide of lead.

A storage battery, therefore, is a device which receives electrical energy, and transforms it into chemical energy, and which again transforms this latter into electrical energy when the cell is being discharged. During this process some of the energy is wasted in heat and in decomposing the solution. The dissipation of energy occurs while the cell is being charged and again when it is being discharged. About 30 per cent of the total power is thus lost.

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A storage battery, after it is charged, possesses nearly all of the features of a primary battery. The gradual transformation of the lead plates into oxides, whose relationship to each other in the acid solution gives rise to a current, makes it clearly evident that the oxides are responsible for the result although they themselves are the direct effect of electrolytic action.

The Inventions of Brush and Faure

Charles F. Brush in America took out patents on a rather different type of plate from that known as the Plante. Camille Faure, of France, laid claim to the same general improvement as that about to be cited. He argued that the development of the lead oxides on the

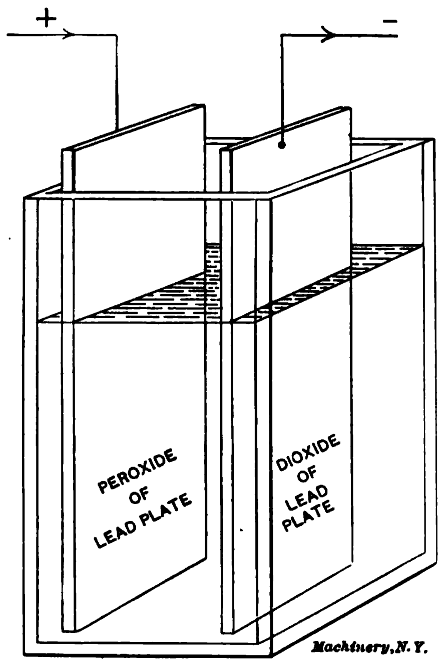

Fig. 38. Practical Form of Storage Battery

lead plates through the "forming" process is necessarily a slow and expensive method and proposed to hasten it by the application of lead oxides to the surface of the lead. A red lead paste was originally applied to both plates, and this, by the action of the current, was reduced to the oxides found on the original Plante plate. Eventually a lead grid, Fig. 39, was invented, in the openings of which the oxides were pasted. Red lead paste was applied to the positive, and a paste made of litharge to the negative grid. By this means intimate contact was secured between the grid and paste and it became easier to obtain what is called "an active surface."

The pasted grid plate has the advantage of both lightness and ca-

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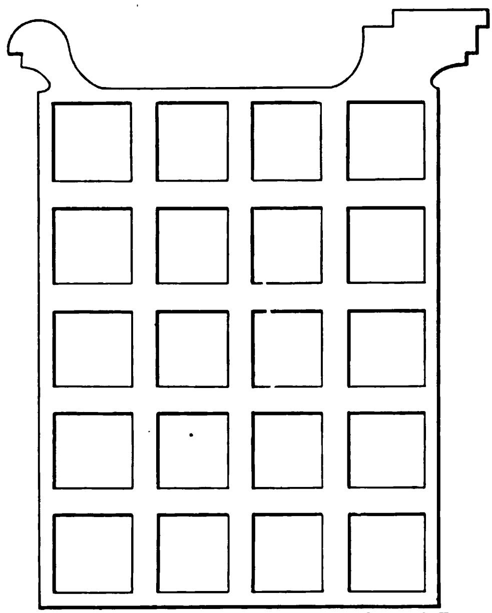
pacity and thus improves the utility of the storage battery in this respect. A Plante plate is very weak unless reinforced by the use of thick lead. Grids, however, can be made of an inoxidizable material to resist deformation. For automobile service, as well as for station use, the storage battery has found a distinct field.

Defects of Storage Batteries

The defects of storage batteries may be classified under the two following heads—sulphating and buckling. The first, sulphating, is due to the plates being left in the acid solution uncharged. The second, buckling, is due to the discharge being too heavy and thus bending or buckling the plates.

Sulphating is avoided by keeping the batteries charged, never allowing the charge to fall below a certain point. The means for detecting



Machinery, N. Y.

Fig. 39. The Lead Grid to which Paste is Applied

when the charge falls below the required point is to be found in the voltage of the cell. When fully charged its voltage is 2.2 and when being discharged it should not be allowed to fall below 1.9 volts. By adhering to this rule sulphating is avoided. The action of the acid on the lead forms a whitish cement-like coating, which consists of sulphate of lead. This can be scratched off only with great difficulty, but may be eventually transformed into an oxide by continued charging. A strongly built plate will resist the warping influence of a heavy discharge. The standard types found in the open market are built on these lines and serve the purpose expected of them satisfactorily.

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Capacity of Storage Batteries

The area of the plates governs their capacity, as well as the amount of active material they contain. One cell with twice the plate surface of another cell would have about twice the capacity, other things being equal. Catalogues of the manufacturers of storage batteries will supply this data, which varies with each particular style of plate. The rating is given in ampere-hours, which means a given strength of current for a given number of hours, a greater current for less hours or less current for a greater number of hours.

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NUMBER 74

PRINCIPLES AND APPLICATIONS OF ELECTRICITY

By Newton Harrison

PART II

MAGNETISM—ELECTRO-MAGNETISM—ELECTROPLATING

CONTENTS

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CHAPTER I

MAGNETISM

The ancients had many legends founded upon the wonderful properties of the lodestone. In the Arabian Nights, Sinbad the Sailor describes the destruction of the vessel in which he and his companions sailed, by approaching too close to a mountain of lodestone. The nails were drawn from the vessel and it fell to pieces. The lodestone was originally found in Magnesia, from which was derived the name magnet. From a chemical standpoint it may be represented by the formula Fe_3O_4, which means a combination of iron and oxygen, forming an oxide, sometimes called magnetite. This mineral possesses permanent magnetic properties, by which is meant that it has the power of attracting light fragments of iron, and holding them with considerable tenacity.

Sir Isaac Newton, the distinguished discoverer of the laws of gravitation, was very proud of a piece of lodestone he possessed set in a ring. It was powerful enough to lift several hundred times its own weight, and in addition betrayed the presence of poles. By this is meant, that at certain points in this mineral, the power seems to be concentrated, and this may be considered as the chief peculiarity of the lodestone.

If we dip a lodestone into a cup of iron filings, and then withdraw it, it will be noted that the filings cluster at each end very thickly. This is merely a manifestation of the peculiar property of all magnets whether natural or artificial—they have two poles. At these points (see Fig. 1), an emission apparently takes place, to which the old experimenters gave the name of magnetic fluid, but which in the language of modern science, is called a magnetic field.

Magnetic Field and Magnetic Poles

Perhaps no more familiar instance of the presence of a magnetic field can be given, than that of the earth itself. Like the lodestone it possesses poles and similarly sends out that remarkable emanation called a magnetic field. For this reason the earth exerts an influence upon a piece of lodestone suspended by a light thread. The lodestone will slowly swing until it has assumed a certain position, to which it will inevitably return, no matter how often displaced. This shows clearly, that the earth exercises a directive effect upon a lodestone, and in consequence the end of the lodestone pointing north has been called the north pole.

It has been stated on good authority that lodestones have been used by the Chinese for many centuries as compasses or guides to the geographical north. Whether this be correct or not, it is well known that by rubbing a piece of tungsten steel with a lodestone, the magnetic

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properties of the lodestone are imparted to the steel, and that the steel will act in all respects as the lodestone itself. It will possess poles, and naturally a magnetic field. If properly mounted, it will swing around and point north, and, in fact, it becomes an indispensable agent of civilization, namely, a compass needle. If the end of a magnet pointing north is called a north pole, it is but a step to conclude that

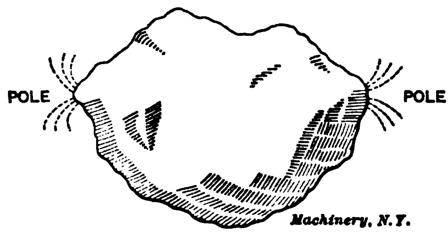

Fig. 1. Poles of the Lodestone

the other end must point south, and will be called a south pole. From this conclusion arises a line of demarkation between the two poles.

If two pieces of steel are magnetized, and mounted as in Fig. 2, so as to swing freely, they will turn so as to present opposite poles to each other. It is useless to attempt to turn them from their positions with regard to each other in this respect. They will inevitably return to the position which brings the north and south pole nearest to each other,

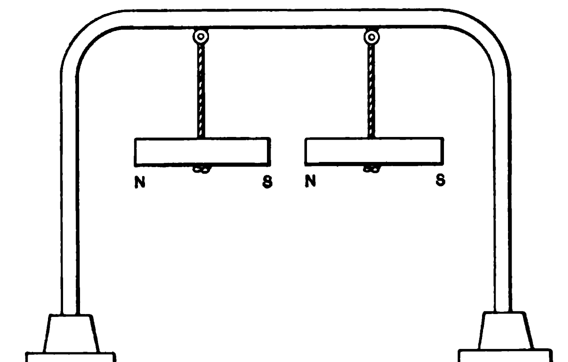

Fig. 2. Swinging Magnets, Demonstrating that Opposite Poles Attract Each Other

and, in fact, they betray a repulsive force when an attempt is made to place them with like poles in proximity to each other.

This has led to the discovery of the operation of certain laws, which may be stated in the following manner:

Unlike poles attract each other.

Similar poles repel each other.

It has, owing to the principles expressed by these laws, become a matter of argument as to which is really the north pole of a magnet

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with respect to the earth. According to the above laws the end of a magnet pointing north would be a south pole, as this is the only pole the north pole of the earth could attract. By some it is called the "marked pole" or the "blue pole," and finally it is termed by others, rather sensibly, the "north seeking pole." The navigator and scientists in general call it the north pole, in spite of this fact, and it will be so called in the present treatise.

The Geographical and Magnetic North

Lest there should be any misapprehension regarding the relative positions of the geographical and magnetic poles, which are entirely

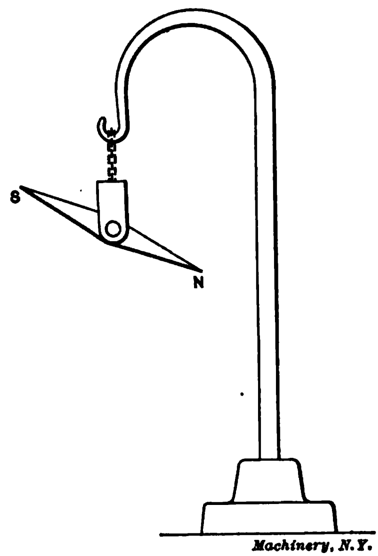

Fig. 3. The Dipping Needle

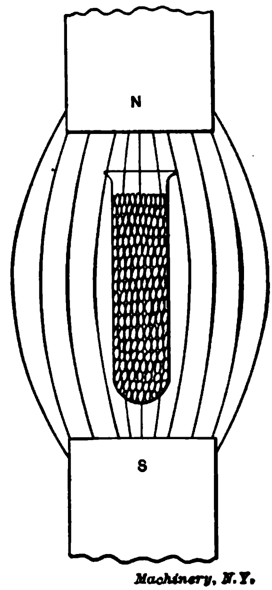

Fig. 4. Tube with Magnetized Iron Filings

different, it may be stated at once that the geographical north pole of the earth is a geometrical point on the earth's surface. On the other hand, the magnetic north pole is located somewhere in the neighborhood of Hudson Bay, Canada.

A magnetic needle supported on a horizontal axis becomes what is commonly known as a dipping needle. At the equator the needle would practically have no dip. But as it is moved north or south a few hundred miles either the north end or the south end begins to dip, as shown in Fig. 3. If moved north until it approaches the magnetic north pole, the dip becomes very pronounced, and if placed over the magnetic north pole, the north pole of the needle would point directly down. From the standpoint of practical utility, however, the movement of the needle in a horizontal plane, as a compass, is of the

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most direct importance. In navigation, allowance is made for the difference between the magnetic and geographical north in steering a vessel.

Magnetic Induction

If a magnet is held near a piece of iron, even though no contact takes place, the piece of iron develops poles, as shown at *A* in Fig. 5. The influence of a magnet upon a neutral piece of iron or steel is called

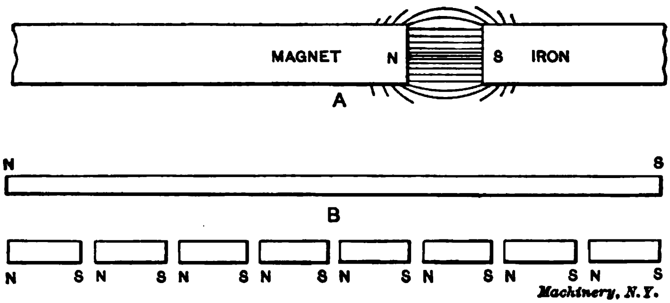

Fig. 5. Graphical Illustrations of Magnetic Induction and of the Magnetic Properties of Molecules

magnetic induction. This explains the attraction which results before contact takes place, and also shows how such attraction can be explained in the light of the law which states that unlike poles attract each other. If a piece of hardened steel is thus exposed to the influence of a magnet it becomes permanently magnetized, that is to say, it will retain its magnetic properties after the source of magnetism has been removed. A piece of soft wrought-iron will not hold its magnetism like steel. Therefore, as both can exhibit magnetism, in the one

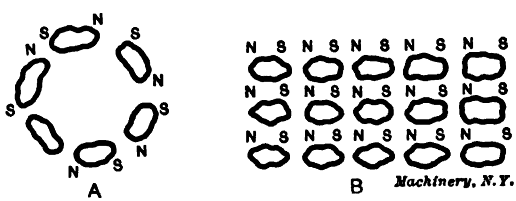

Fig. 6. Arrangement of Molecules in an Unmagnetized and in a Magnetized Piece of Iron

case permanently, and in the other case temporarily, they are called permanent magnets and temporary magnets.

Theory of Magnetism

The theory of magnetism is based upon the idea that it is a molecular phenomenon. The molecules of iron and steel differ in this respect, that when the molecules of steel are disturbed by magnetism they are not free to move back to their original position, whereas in the case of wrought-iron, they possess this power. According to this theory, and an experiment about to be described, every molecule of iron and steel

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is by nature a magnet. The means by which this idea is proved is as follows: A long steel needle or wire is carefully magnetized and its poles tested by a compass needle. It will be found to have a north and south pole. The wire is cut in half and then tested. Each half will be found to possess a north and a south pole. A repetition of this process will reveal the fact that every piece of steel has become a magnet with two poles, as shown at *B* in Fig. 5. If one of these pieces of steel is supposed to be divided and subdivided beyond the practical limits possible, a point is reached where a molecule of steel is obtained. This molecule, according to preceding experiments, must pos-

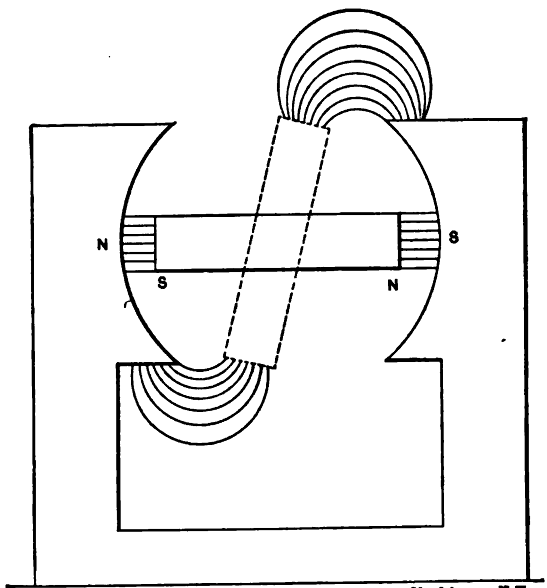

Fig. 7. Graphical Illustration of the Action of Magnetic Forces on a Piece of Iron Pivoted at the Center of a Magnetic Field

sess a north and south pole. With regard to this polarized molecule, it may be said that the assumption of its existence is indispensable at present in relation to the explanation it gives of most of the magnetic phenomena observed in connection with iron or steel.

If a test tube is filled with iron filings and exposed to a magnetic field, as shown in Fig. 4, the filings will arrange themselves in an end to end manner, each particular grain of metal placing itself so as to bring its opposite poles in contact with the opposite poles of its neighbor. When removed from the magnetic field, the filings, of course, become disarranged. The experiment seems to indicate that magnetism in iron or steel is equivalent to a certain position of the molecules. If a piece of iron or steel is not magnetized the molecules are irregularly arranged, that is to say, they do not point end to

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end throughout the length of the iron rod. In fact, the molecules are arranged in small closed magnetic circuits which effectively shut off all external signs of magnetism from the body as a whole. These rings of magnetic elements are composed of what are called polarized molecules, that is to say, infinitesimal permanent magnets, whose natural position is that illustrated at *A* in Fig. 6. When the magnetic field affects them, however, they are torn or forced from this position and arrange themselves as shown at *B*. By this means one end of the bar becomes north pole and the other south pole, and it is easy to see that the fracture of the bar at any point whatsoever would result in opposite poles appearing, each at the respective ends of the fractured section. Therefore, when a permanent magnet is broken in half, two magnets appear; if broken again, four magnets are produced, etc.

One of the most useful of magnetic principles is that which states that "lines of force tend to arrange themselves parallel to each other."

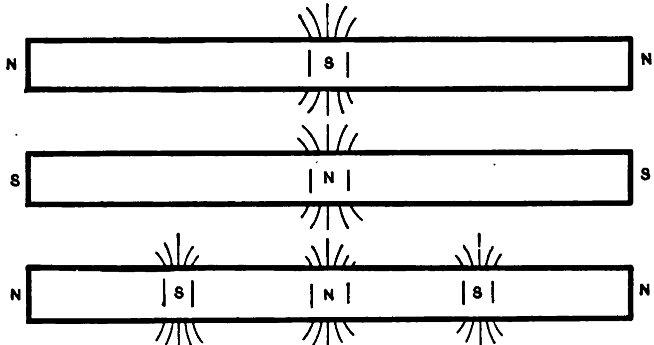

Fig. 8. Magnetized Bars with Consequent Poles

This principle is clearly shown in the repeated efforts of a compass needle, when diverted from its normal position by the finger or another magnet, to return to one in which its lines of force lie parallel to those of the earth. If a bar of iron is held almost at right angles to the magnetic field of a powerful magnet, as shown by the dotted lines in Fig. 7, the tendency of the field to twist the bar around to the horizontal position is due to this principle, and also to the fact that the poles in the bar induced by magnetic induction are thus brought closer to the poles of the magnet.

It is generally supposed that a magnet can only have two poles, but this is not so, as indicated in Fig. 8. Here the magnet has two north poles or it may have two south poles. This would give either a south or a north pole in the middle of the bar. Such a pole is called a *consequent* pole and is, as shown, a pole belonging to each of the magnets of which it constitutes a part. This shows that a magnet as thus understood is not necessarily a bar of steel or iron with a pole at each end, as such a bar may really consist of several magnets, depending upon the magnetization of the bar. For this reason the distribu-

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tion of the magnetic field must be ascertained and investigated by means of a compass needle, otherwise it would be very confusing to find similar poles at the two ends of a magnetized bar.

Horseshoe Magnets

In order to obtain in full the effect of the two opposite poles a bar magnet is bent around, forming the familiar type of the horseshoe magnet, as shown in Fig. 9. This magnet is supplied with an armature of soft iron which is generally left in contact with the poles when not in use. Under this condition, very little, if any, magnetism can be detected outside of the magnet, and it constitutes in this form a closed magnetic circuit.

The lines of force emanating from a horseshoe magnet's poles and sides follow a curved path, as shown in Fig. 9. This can be readily observed by placing a sheet of paper over the magnet and sifting iron filings on it. When they fall, they will arrange themselves in curved

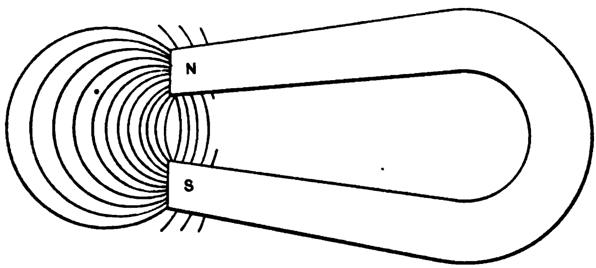

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Fig. 9. The Magnetic Field of a Horseshoe Magnet

lines showing the direction of the magnetic field. At each individual pole they repel each other, because, according to the fundamental laws, north lines repel north lines and south lines repel south lines. But they curve around in spite of this repulsion and meet each other according to the law that the lines of force of opposite poles must attract each other.

A Unit Pole

The exact measurement of magnetism is carried out by basing all calculations upon certain units, which are derived by reference to the centimeter, gram and second system. The unit pole may be regarded as the foundation of such a system and is defined as follows: A unit pole repels a similar and equal pole at a distance of one centimeter with the force of one dyne. Thus, the measurement of magnetism is based upon an idea easily comprehensible. A magnet repelling another magnet with a given degree of force, is thus named in accordance with the requirements of the definition.

Were the magnetic poles so powerful that the repulsion could be measured in pounds, then the principle would be capable of demonstration with exactitude on a large scale. But this is not the case, and the force developed is very small.

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The Permeability of Iron or Steel

Lines of force enter iron or steel and produce within iron and steel a polarized condition of the molecules. If the magnetic field between the poles of a powerful magnet is taken as a basis for experiments, then the following facts will be noted if equal sized bars of cast iron, steel and wrought-iron are tested:

Experiment with cast iron:—Pull very strong.

Experiment with mild steel:—Pull stronger.

Experiment with wrought-iron:—Pull greatest of all.

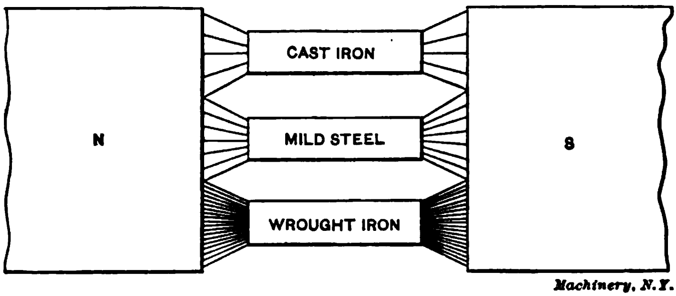

Fig. 12. Graphical Illustration of the Permeability of Different Metals

The meaning of this experiment is as follows: The number of lines of force the cast iron develops are less than those of either the steel or wrought-iron. (See Fig. 12.) If the number of lines of force are any measure of the pull of a magnet, then the cast iron, mild steel and wrought-iron differ from each other as far as magnetism is concerned. If a bar of each of these metals of one square inch cross-section is exposed to the influence of a powerful magnetizing force, then if some means were provided by which the magnetism or number of

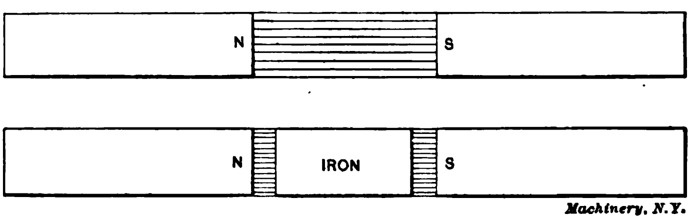

Fig. 13. The Number of Lines of Force through Air and through Iron

lines of force excited in each of these bars, respectively, could be measured, some comparison could be made between them for the purpose of discovering in what respect and to what extent they differ.

By employing an electric current in connection with a large electromagnet, sufficient magnetism can be obtained to make a test of each of these bars. A button of wrought-iron attached to a spring balance, as shown in Fig. 14, with a little reel to gradually develop the pull is all that is required. The wrought-iron, according to such an experiment, will then show the greatest pull in pounds, then comes the mild steel

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and finally the cast iron. It is possible to test any sample of iron or steel by this means, and if the device is well constructed, considerable accuracy is attainable. The three metals referred to are greatly used in the construction of electrical machinery.

It is evident that if magnetizable metals behave in this manner, it is necessary to use some distinguishing phrase to mark this difference. The term "permeability" is employed for this purpose, and the metals are referred to by saying "the permeability of wrought-iron is greater than that of steel," or "the permeability of steel is greater than that of cast iron," etc.

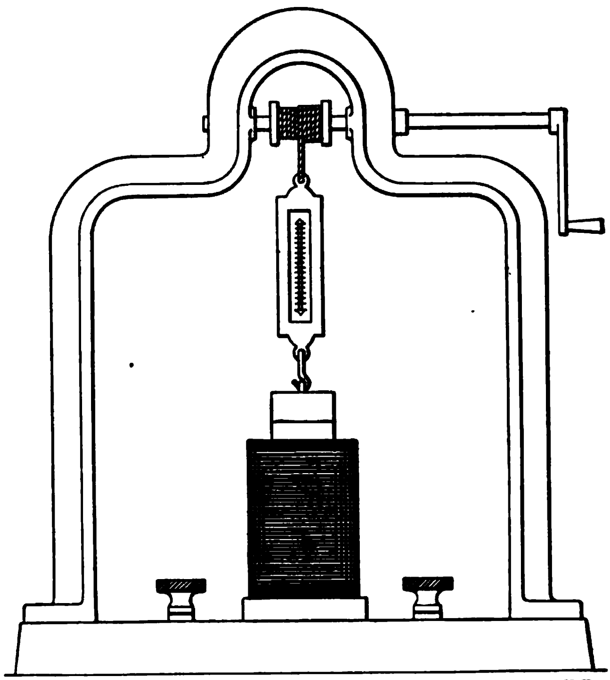

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Fig. 14. Measuring the Pull of a Magnetized Iron Core

The permeability is expressed as the ratio between the strength of a magnetic field with iron in the field, and with iron out of the field, the lines of force in the latter case passing simply through the air, as shown in the upper view in Fig. 13. Suppose the number of lines of force between the poles of a magnet is measured, and then when a piece of iron whose permeability is to be discovered is placed in this magnetic field, as in the lower view in Fig. 13, its field is also tested. If the lines of force of the iron are divided by the lines of force of the original field the permeability is obtained. The permeability is generally represented by the Greek letter μ (mu), and the formula is as follows:

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$$\text{Permeability} = \frac{\text{Lines of force in iron}}{\text{Lines of force in air}} = \mu.$$

It can, therefore, be said that permeability is a natural qualification of magnetizable metals. Why one has more permeability than another is, in all probability, dependent upon the ease with which the molecules move when magnetized; but there is no distinct criterion for this, and the two extremes of permeability as found in daily practice are that of air and Swedish wrought-iron. Air is taken as the standard and is said to have a permeability of 1. Wrought-iron has a permeability of at least a thousand, depending, of course, upon its quality. The lines of force are measured with reference to the square centimeter or square inch. In bars of equal size, the greater the number of lines per unit area, the greater the magnetic pull.

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CHAPTER II

ELECTRO-MAGNETISM

It is customary to term magnetism produced by electricity *electro-magnetism*, to distinguish it from that which has been produced by lodestones and permanent magnets. Permanent magnets can be made by electro-magnets as well as by the lodestone or other permanent magnets. In fact, the permanent magnet is simply a special case of retained magnetism, while in the production of electro-magnetism, either no iron is used at all, or, if employed, it is what is generally known as soft or wrought-iron or mild steel—a magnetizable material which does not retain its magnetism permanently. Many expressions are in use in relation to magnetism, such as natural magnets, artificial

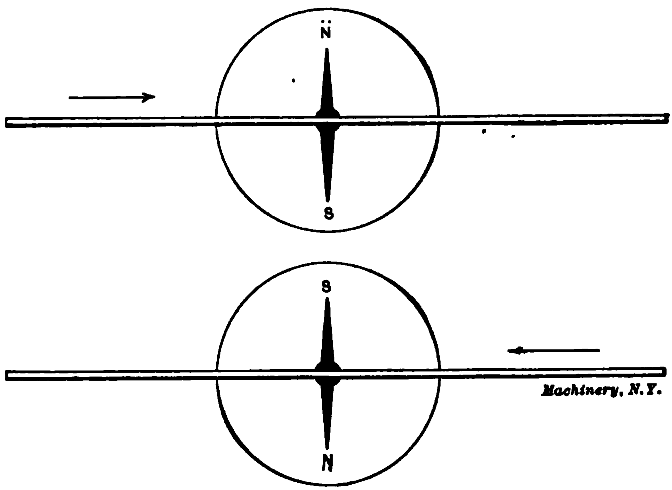

Fig. 15. The Effect of an Electric Current on a Magnetic Needle

magnets, permanent magnets, and temporary magnets. There are other phrases and words, some obsolete and some modern, which do or did apply to the subject of magnetism. Many of these are unscientific and misleading and it is best to cling to the later and more correct titles of to-day. If magnets are classified, irrespective of other considerations, as permanent magnets and electro-magnets, a beginning can be made for a correct practical and theoretical consideration of electro-magnetism. The last is what constituted the discovery of Oersted, namely that an electric current produced all the characteristics of a magnet.

If a copper wire is used to carry a current of electricity from one pole of a battery to another, the entire wire will be found to be sur-

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rounded by magnetism. This magnetism, or lines of force, as it is more properly called, can be detected by bringing a compass needle near the wire, as shown in Fig. 15. The needle will be affected to such a marked degree and in such a manner that it will place itself at right angles to the wire. Another curious phenomenon will be noticed. While the current is flowing in one direction through the wire, the needle will hold its position at right angles, as described, but if the current in the wire is reversed, the needle will swing around, and although it will settle itself at right angles to the wire in this case as well as the other, it will be discovered that the positions of the poles have changed—they have reversed.

If the wire carries a very powerful current and it be thrust through a sheet of cardboard and iron filings scattered around, the presence of concentric circles of filings will be apparent upon lightly tapping the cardboard. The presence of magnetism as thus shown, simply proves

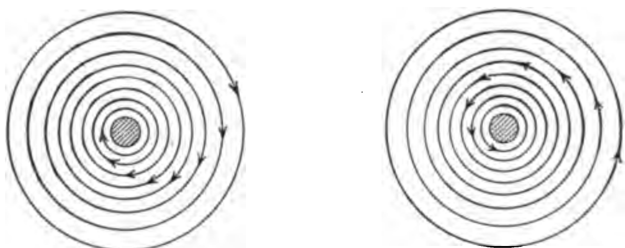

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Fig. 16. Magnetic Whirl around a Wire Carrying an Electric Current

the existence of a magnetic field whose center is the wire and whose influence extends beyond it. The experiment of reversing the current, however, shows by the reversal of the poles of the adjacent magnetic needle, that the magnetic field around the wire has reversed as well. The wire which carries a current is apparently the seat or source of a magnetic whirlpool. The direction of this whirlpool looking at the wire endwise, as in Fig. 16, is entirely a question of the direction of the current. Knowing this as an established fact of the greatest consequence in everyday practice, it is not difficult to explain why the needle reverses its poles with the reversal of the current.

The lines of force of a magnetic needle pass out of the north pole and return to the south pole after describing a path through the surrounding space, which can be indicated by means of iron filings, as mentioned in the previous chapter. It is only for purposes of convenience that this assumption is made, as either pole may be regarded as the one from which the magnetism issues, provided this pole is distinguished from the other. A wire carrying current also represents a case where the lines of force surrounding it have a definite direction. Bringing a current-carrying wire and a compass in close juxtaposition, has the effect of forcing the needle to a right-angled position, simply because the lines of force of the needle and wire, instead of

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opposing each other, place themselves in such a position as to become parallel to each other. The needle, being free to move, responds to this tendency, and thus illustrates the principle that *lines of force tend to arrange themselves parallel to each other.*

In this particular case the lines of force of the wire direct the position of the freely moving needle, and its north pole points along the

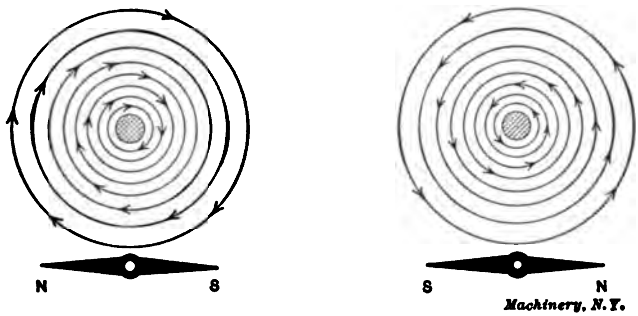

Fig 17. Relation between Direction of Magnetic Whirl and Position of a Magnet Needle

direction of rotation of the magnetic field or whirl around the wire, as shown in Fig. 17. If the current is reversed in the wire, the magnetic whirl reverses and the needle likewise, in accordance with the principle enunciated.

Attractive and Directive Action

The law, that unlike poles must attract each other, explains the phenomenon of magnetism so far as the actual movement of opposite poles

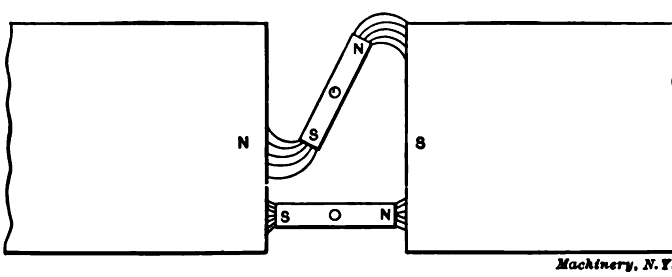

Fig. 18. Graphical Illustration of the Tendency of the Lines of Force to Set Themselves Parallel to Each Other

is concerned, but when the action of the earth's magnetic field upon a compass needle is considered, it becomes evident that here the action is directive, due to the fact that the lines of force of the earth and the needle set themselves parallel to each other.

When a soft iron bar is placed in a magnetic field, as in Fig. 18, it becomes magnetized through induction, and hence, being for the time a magnet, its lines of force, so to speak, endeavor to pull toward the lines of force of the original field and in this way a twisting or

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turning tendency is developed, forcing or tending to force the bar into a position in which it lies parallel to the magnetic field surrounding it. This directive influence, as well as the actual attraction, are the sources of mechanical energy found in electric motors.

The discovery of Oersted led him to regard a turn of wire carrying a current as the equivalent of a flat magnet. On bringing a compass near a loop of wire carrying a current, the needle will act as if the current-carrying turn of wire were a magnet itself. In fact, this is so; the lines of force surrounding the wire will produce on one side a north magnetic pole, and on the other side a south magnetic pole. The lines of force issue from one side of the loop and pass around

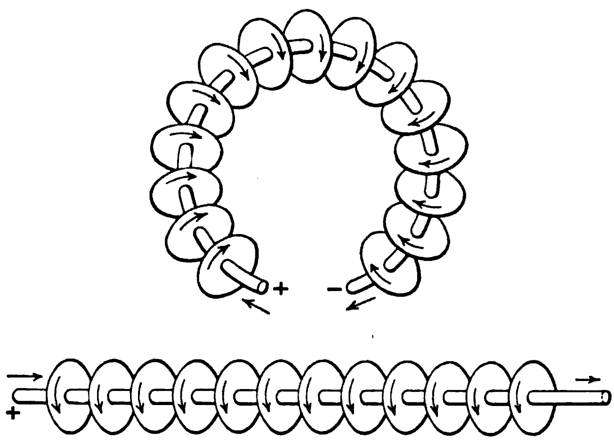

Fig. 19. Graphical Illustration of the Direction of Current in a Wire and the Magnetic Whirl Around It

through space to the other. The idea can be best represented, as in Fig. 19, by a number of wheels on a metal rod, all rotating in the same direction, whether the rod remains straight, is bent, or brought around into a loop. Looking at one side of this loop, the rims of the wheels are rotating outwardly, and on the other side they are entering. In a similar manner the lines of force ceaslessly rotate around a current-carrying wire as an axis, only reversing their direction of rotation when the current in the wire is reversed. If the wire remains in the form of a loop, and the current in it is reversed, the side of the loop from which the rotation or direction of the magnetic lines emanates in the first place will now be the side in which they will enter instead of leaving, and *vice versa*.

Poles and Direction of Current

A new and very important fact now presents itself with respect to the loop of wire carrying a current. When the needle is brought near one side, the north pole of the needle is attracted, and when it is pre-

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sented to the other side the south pole of the needle is attracted. If the direction of the current is noted with respect to the direction of motion of the hands of a clock, it will be seen that the current appears to pass in the wire coil from one side in a direction *opposite* to the hands of a clock, and from the other side *with* the hands of a clock. In other words, the direction of flow of the current will be dependent

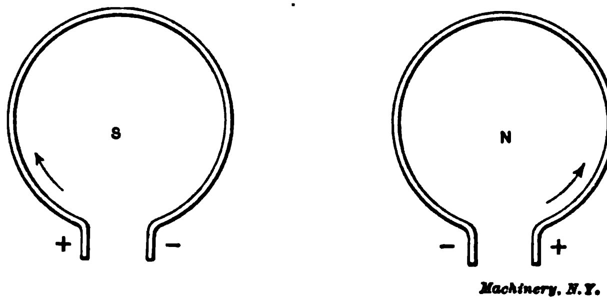

Fig. 20. Relation between Direction of Current and Polarity

upon the end of the coil nearest to the point of observation. It will be found that on that side of the coil where the direction of the current is opposite to the motion of the hands of a clock, a north pole appears, and conversely, on the other side of the current-carrying loop, where the current circulates from its positive to its negative pole in a direction *similar* to the movement of the hands of a clock, a south pole ap-

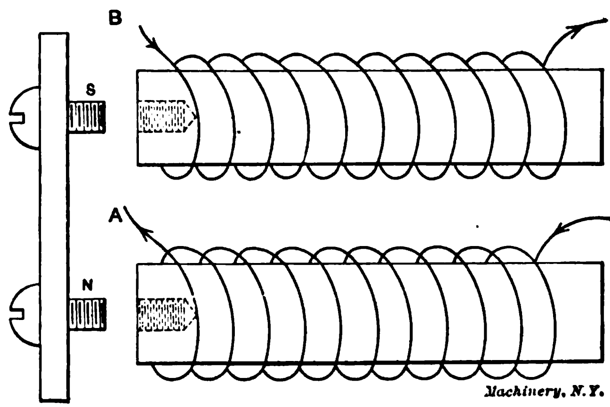

Fig. 21. Method of Winding Electro-magnets

pears. Here then is a means of pre-determining the north or south pole of a coil with reference to its winding and the flow of the current; *with* the hands of a clock a *south* pole, *opposite* to the hands of a clock, a *north* pole. (See Fig. 20.)

Winding Magnets

It will now be understood that the method of obtaining two different poles in an electro-magnet becomes merely a question of connecting the

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ends of the coils correctly. Fig. 21 shows two cores wound with a single layer of wire to exemplify the principle. Here all the elements of the ordinary magnet are found: two soft iron cores and the connecting bar of soft iron, or keeper, with screws to hold the parts tightly together. The illustration shows that on both cores the winding is wound in the same way. This requires that the two end wires *A* and *B* be twisted together to give opposite poles at the ends of the cores. The coils of wire may be wound on sleeves, and then after soaking in melted paraffin or shellac slipped off, and put aside for future use. In this manner a great many coils can be prepared for magnets before they are assembled. It is only necessary to see that when they are slipped on the cores the windings all begin at the same end. If the direction of the current is traced in the illustration given, it will

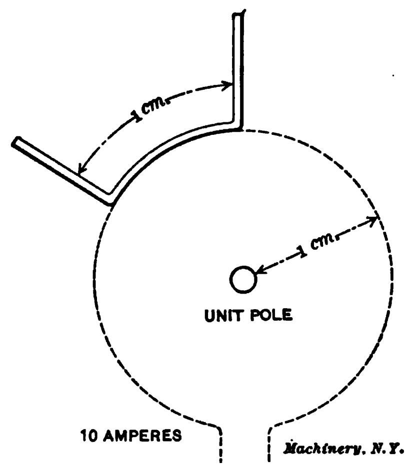

Fig. 22. Graphical Illustration of the Method used for Defining the Unit of Current

be seen that the polarity is indicated on the basis previously stated. If the coils of a magnet are not placed or wound so as to require the ends most conveniently connected to be brought together, then the only recourse is to carefully trace the direction of the current, and connect the ends that will give opposite poles, even though wires are connected from the opposite ends of each coil.

Unit of Current

The magnetic effect of a turn of wire through which a current is flowing has been utilized in arriving at the value of a unit of current. A whole turn of wire is not used, but only one centimeter. This centimeter length of wire forms an arc which constitutes part of a circle of one centimeter radius, as shown in Fig. 22. In other words, if a circle of wire is constructed of unit radius, and if only a unit length of this circle of wire is employed to carry a current, then when the current in this one centimeter of wire of one centimeter radius is

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sufficiently strong, it will exercise a magnetic force on a unit magnetic pole equal to one dyne. The current which is able to exercise a force of one dyne in a centimeter of wire of one centimeter radius upon a unit north pole placed at the center, is a current of 10 amperes. The absolute unit of current is thus not the unit commonly employed, but is equal only to one-tenth of the absolute unit and called one ampere.

The development of. a mathematically exact quantity of force by every equal length or portion of a wire carrying a current of uniform strength, is one of the fundamental propositions of magnetism.

Laws of Electro-magnetism

In practical work it is possible to calculate with the greatest accuracy results in electro-magnetism by using a simple law embracing all of its applications. In order to fully grasp the idea it represents it is necessary to know the meaning of the constituents by which it is presented for practical use and through which the relationship between the parts of an electro-magnetic circuit are best understood.

The electro-magnet consists of a coil of wire carrying a current and either possessing a core of iron or not, as the circumstances require. It will be understood that the production of magnetism depends upon the number of loops of wire carrying a current. It is also evident that not only are the number of loops to be considered, but the strength of current they carry as well. Hence, the greater the number of turns or loops of wire and the greater the current in these turns, the greater the magnetic effect produced in total. It is customary to speak of the loops of wire as turns and the combination of current and turns as *ampere-turns*. From a purely physical standpoint the "magnetism producing" elements of an electro-magnet are the ampere-turns. These are obtained by multiplying the turns of wire composing the magnet by the amperes passing through, the total representing ampere-turns. For instance, if an electro-magnet consists of 1000 turns carrying a current of 10 amperes, the ampere-turns = 10 × 1000 = 10,000. If the turns are 1000 and the current is decreased to 1/10 ampere, then the product equals 1/10 × 1000 = 100 ampere-turns. If, for example, there are 10,000 turns and 1 ampere, or 1 turn and 10,000 amperes, then in either case the total ampere-turns equal 10,000, which means that the *magneto-motive force* is the same. A graphical illustration of the relation between number of turns, amperes, and lines of force is shown in Fig. 23.

In calculating the magneto-motive force, the ampere-turns are multiplied by 4π giving as the total value $4\pi nc$ where $\pi = 3.1416$, n = turns, c = amperes. For instance, the magneto-motive force of a coil of 1000 turns carrying 10 amperes is equal to 4 × 3.1416 × 10 × 1000, = 125,664.

If the current is reduced the magneto-motive force is reduced correspondingly, and the power of the coil to force magnetism through an iron bar is also reduced.

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The magneto-motive force, therefore, bears a distinct relation to the ampere-turns required to force magnetism through a bar of iron. If the bar is long it would require more magneto-motive force to produce a certain number of lines of force throughout than if the bar is short. In other words, the dimensions of the iron bar, its length, breadth and thickness, will have to be considered in conjunction with the magneto-motive force in order to arrive at a clear and adequate idea of the conditions governing the development of a magnetic field produced by electro-magnetism.

The law of electro-magnetism states that *the magnetic flux is directly proportional to the magneto-motive force and inversely proportional to the magnetic reluctance.*

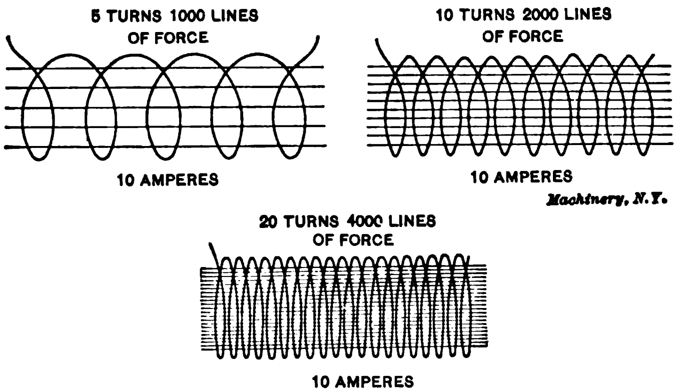

Fig. 23. Graphical Representation of the Effect of an Increasing Number of Ampere-turns

This can be represented in the following form:

$$\text{Magnetic flux} = \frac{\text{Magneto-motive force}}{\text{Magnetic reluctance}}$$

The magnetic flux and reluctance will each be treated separately and will be found to represent, respectively, first, the number of lines of force produced, and, secondly, the conditions through which the magneto-motive force must operate to produce the magnetic flux. These conditions consist of the dimensions of the space or material through which the magnetism is being produced and the permeability of the material magnetized.

Magnetic Reluctance and Permeability

The reluctance of a material to be magnetized calls for a greater or less magneto-motive force to produce a given magnetic flux, the same as the greater the resistance of an electric circuit, the greater the electro-motive force required to send through it a current of given strength. The reluctance of any magnetic circuit consists of four items, three of which are dimensions and the fourth is the peculiarity of the material called permeability, which has already been referred

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to in the previous chapter. The dimensions are naturally the length, breadth and thickness, or the length and cross-section of the material undergoing magnetization.

Permeability, as previously mentioned, is the ratio between the lines of force in iron and the lines of force in air.

$$\text{Permeability of iron} = \frac{\text{Lines of force in a magnetized bar}}{\text{Lines of force without iron}}.$$

For instance, if the magneto-motive force of a coil carrying a certain current produces 10,000 lines of force in air, which when a bar of iron is inserted increase to 10,000,000, then the permeability or multiplying power of the iron can be represented by the ratio of 10,000,000 to 10,000, or

$$\text{Permeability} = \frac{10{,}000{,}000}{10{,}000} = 1000.$$

Many cases could be cited to illustrate the meaning of permeability in iron, steel or air which would disclose the fact that in the softer grades of iron like wrought-iron and mild steel the permeability is higher than in cast iron or any of its modifications.

As stated in the previous chapter, air is taken as a standard of permeability and is called 1. In comparison the magnetizable metals rate very high and range according to the following schedule as regards their permeability:

Air	1
Cast Iron	800
Mild Steel	2,000
Wrought-iron	3,000

The result of a lower permeability is less lines of force when the same magnetizing force is employed by means of a coil. This idea can be well represented by making three bars of cast iron, wrought-iron and steel, of exactly the same dimensions, and placing them in three coils of the same number of turns and supplied with exactly the same current apiece, as shown in Fig. 24. This would give the same magneto-motive force to each coil and the same dimensions to each magnetizable bar; the only difference would be found in the different permeabilities of the metals respectively.

Formulas and Examples

The law that the magnetic flux is proportional to the magneto-motive force and inversely proportional to the reluctance can now be represented symbolically as follows:

$$F = \frac{M}{R}$$

in which F = flux, M = magneto-motive force, and R = reluctance.

If the magneto-motive force is expressed by $4\pi nc$ and the permeability is represented by the Greek character μ, then the flux can be calculated by the following formula which presents exactly the same proposition

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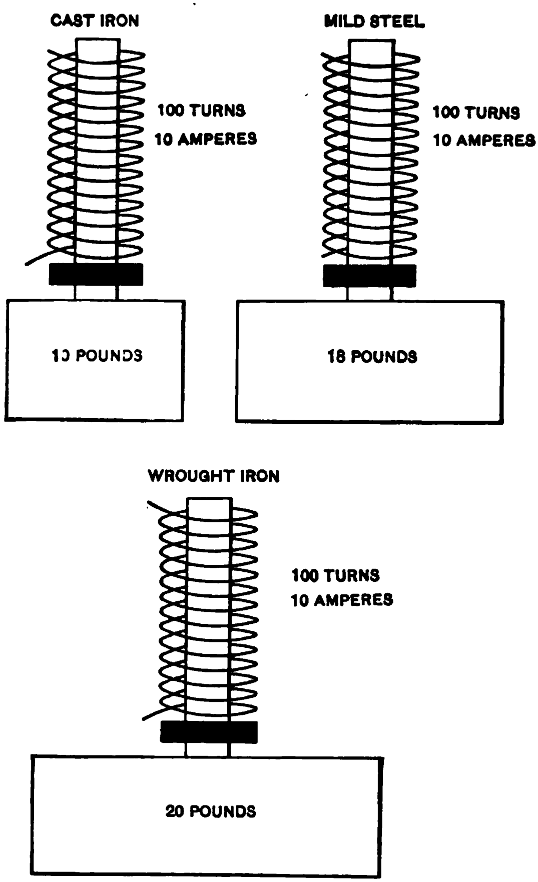
but has a symbol for all the elements which compose a problem of this kind:

$$\text{Lines of force} = \frac{4 \times \pi \times n \times c \times \mu \times q}{10 \times l}$$



Machinery, N.Y.

Fig. 24. The Difference in Effect of the Same Number of Ampere-turns on Cast Iron, Mild Steel and Wrought-iron

in which $4\pi n\,c$ = magneto-motive force,
μ = permeability,
q = cross-section of iron in square centimeters,
l = length of iron in centimeters.

To show the application of the formula, suppose a coil has 500 turns and carries 2 amperes. The iron has 10 square centimeters cross section and is 20 centimeters long, with a permeability at that point of magnetization of 1000; how many lines of force will be produced?

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$$\text{Lines of force} = \frac{4 \times 3.1416 \times 500 \times 2 \times 1000 \times 10}{10 \times 20} = 628{,}320.$$

The formula can be transformed to suit the requirements of the English system by making every centimeter equal to 0.4 of an inch, or 1 inch equal to 2.5 centimeters, and every square inch equal to 6.25 square centimeters.

The formula just given may be written as below:

$$\text{Lines of force} = \frac{4\,\pi n\,c}{10\left(\dfrac{l}{\mu\,q}\right)}.$$

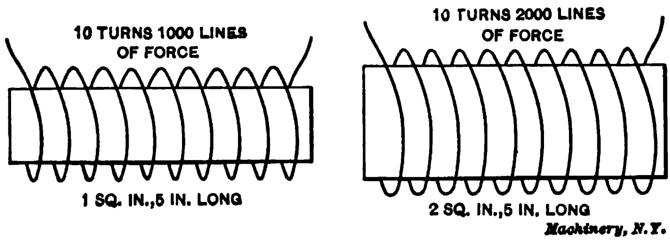

Fig. 25. The Effect of Reduced Reluctance

Here the μ and q have been placed in the denominator to constitute what is called the reluctance, thus giving as the elements of the formula:

$$\text{Magneto-motive force} = 4\,\pi n\,c$$

$$\text{Reluctance} = \frac{l}{\mu\,q}$$

The factor 10 in the denominator reduces amperes into absolute units of current which are equal to 10 amperes. If 10 amperes were employed in the coil only 1 absolute unit of current would appear in the formula. It is clear from the formula that if the reluctance becomes less, the lines of force will increase with the magneto-motive force remaining the same. If the reluctance increases, the lines of force diminish if the magneto-motive force remains the same. Fig. 25 graphically illustrates the effect of reduced reluctance. If the formula for the reluctance is examined it will be found that the reluctance can only be increased by increasing l or the length of the magnetic circuit, or decreasing μ or q, the permeability and cross-section of the circuit. On the other hand, the formula, as given, shows that a great magnetic reluctance can be compensated for by increasing the magneto-motive force.

Winding Magnets

The winding of magnets is accomplished by considering first the number of lines of force per unit of area of cross-section and, secondly, the number of ampere-turns required to produce a uniform magnetic con-

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dition throughout the iron, steel or air under process of magnetization. The number of lines of force per square inch of cross section is the basis of most estimates made in this direction. The estimates of the amount of magnetism produced from a magnetic circuit first became accurate through the application of the method of John Hopkinson, an English scientist and engineer.

This method consists of the division of the magnetic circuit into its separate parts, such as the cast iron, the wrought-iron and the air-gap.

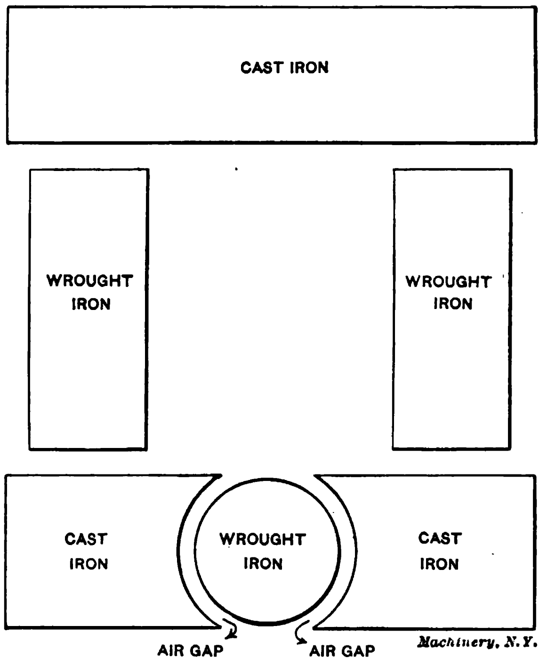

Fig. 26. Diagrammatical View of the Essential Parts of a Dynamo

Each part carries a certain number of lines of force per square inch and has a certain length. In other words, it is necessary to provide a certain magneto-motive force for each distinct part of the magnetic circuit. All of these magneto-motive forces are added together in the shape of a sum total of ampere-turns constituting the field winding. Thus two processes are necessary: First, that of obtaining the total magneto-motive force, and, second, that of obtaining the correct winding, size of wire, etc.

To illustrate the idea involved in the application of the Hopkinson method, take the case of a dynamo, which, as seen in Fig. 26, represents a magnetic circuit composed of many parts—the keeper, of cast iron, the magnet cores of wrought-iron, the pole pieces of cast iron, the armature core of wrought-iron, and finally the air-gap lying between the armature core and the pole pieces. The problem from an every-

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day practical standpoint is that of finding the total number of ampere-turns required to force a given number of lines of force through the armature core from pole piece to pole piece. In order to do this, as stated before, each individual part of the magnetic circuit must be provided with sufficient magneto-motive force to develop in it the amount

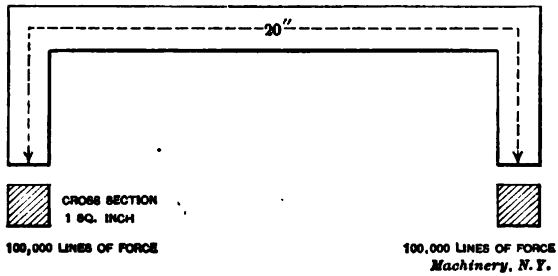

Fig. 27

of magnetism or number of lines of force required to establish this result.

Suppose, for purposes of illustration, that in order to send 100,000 lines of force per square inch through wrought-iron, it takes 92 ampere-turns per inch of length. Then, if the bar is 20 inches long and of 1 square inch cross-section, as shown in Fig. 27, and carries 100,000

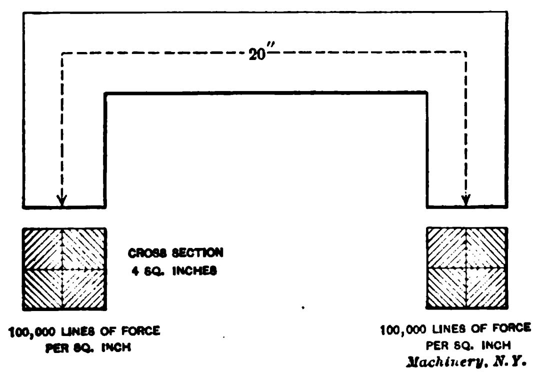

Fig. 28

lines of force, the number of ampere-turns required would be equal to $20 \times 92 = 1840$, to produce the induction, as it is called, per square inch. If a magnetic circuit of the same material, the same length, but four times the cross-section, as shown in Fig. 28, is considered, then the fact to be remembered is this—that here the length of the magnetic circuit has not changed and therefore the magneto-motive force will not be any greater than in the first case; but the cross-section of the iron being four times as great means a magnetic reluctance of one-quarter and, therefore, four times as many lines of force in consequence.

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The same number of ampere-turns would be required for either bar of wrought-iron because the length and quality of the iron of each is the same. Now it does not make much difference whether these ampere turns are placed along the whole length of the bar or at one portion of it. The total number required in this particular case is 1840 to produce 100,000 lines of force per square inch throughout the bar. The bar might have a cross-section of 100 square inches; if it has the same length the same number of ampere-turns will be required to give every square inch of its cross-section an induction of 100,000 lines. The important part is to provide the required number of ampere-turns

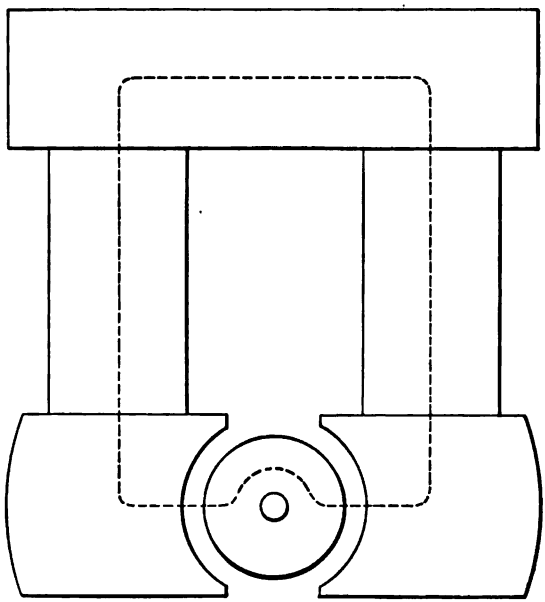

Fig. 29. The Mean Path of the Lines of Force through a Dynamo

per inch length. This number, for different grades of iron or steel, can be obtained from curves or tables. A very important table of this character, prepared by A. E. Wiener, is given on page 30 for the uses indicated, namely, the calculation of the ampere-turns of any magnetic circuit of any material in ordinary use.

The Hopkinson method requires a determination of the following factors:

1.—Lines of force per square inch in cast-iron keeper and the corresponding ampere-turns per inch length.

2.—Lines of force per square inch in wrought-iron cores and the corresponding ampere-turns per inch length.

3.—Lines of force per square inch in cast-iron pole pieces and the corresponding ampere-turns per inch of mean length.

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4.—Lines of force per square inch in wrought-iron armature and the corresponding ampere-turns per inch of length.

5.—Lines of force per square inch of air gap and the corresponding ampere-turns per inch or part of an inch of length.

The selection of the mean path through the parts of a dynamo is shown by the dotted lines in Fig. 29. After getting the total ampere-turns for each part of the dynamo the following schedule is arranged:

Ampere-turns for magnet cores	1000
Ampere-turns for keeper	200
Ampere-turns for pole pieces	300
Ampere-turns for armature core	100
Ampere-turns for air gaps	2400
Total ampere turns	4000

With the total ampere-turns found, the next step is to find the proper size of wire as called for by the electromotive force of the armature which supplies the field winding.

Formula for Size of Wire

The simple formula employed for finding the size of wire to use calls for a knowledge of the total ampere-turns, the volts to be applied to the terminals of the coils, and the average or mean length of one turn. This last is obtained by taking the diameter of the magnet core and adding to it the anticipated depth of winding in inches. Between these two an average is obtained and multiplying by π gives mean length of one turn. The size of wire is given by its area in circular mils.

$$\text{Circular mils} = \frac{\text{Total ampere-turns} \times \text{mean length of turn}}{1.106 \times \text{volts of coil}}.$$

In the case of a dynamo whose total ampere-turns equal 4000, the mean length of a turn equals 12 inches, the size of wire required equals the following at 110 volts:

$$\frac{4000 \times 12}{1.106 \times 110} = 395 \text{ circular mils} = \text{No. 24 B. \& S. gage, approx.}$$

Allowing 1000 circular mils per ampere gives a current of approximately 0.4 of an ampere. Dividing the total ampere-turns already decided upon (4000) by 0.4, gives the number of turns as 10,000; as each turn is one foot, there are approximately 10,000 feet of wire.

The temperature of the coil must also be considered, because the greater the amount of power dissipated in the coil in the form of heat, the higher its temperature becomes. This will destroy the coil unless regulated by the outer surface of the coil itself and the depth of winding. A simple formula gives the temperature in degrees Fahrenheit to which a coil will rise when two things are known, the power (watts) wasted in the coil, and the number of square inches of radiating surface of the coil.

To obtain the power wasted in heat in the coil, the resistance of the wire in ohms must be multiplied by the square of the current. For in-

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UNIT MAGNETO-MOTIVE FORCES

Ampere-turns per Inch Length

Magnetic Density, Lines of Force per Square Inch	Annealed Norway Iron	Soft Cast Steel	Mitis Iron	Cast Iron Containing 6.5 of Aluminum	Cast Iron (ordinary)	Air
2,500	1.2	2.0	2.5	7.0	9.0	783
5,000	1.7	2.8	3.4	9.6	13.0	1,566
7,500	2.1	3.4	4.0	11.6	16.0	2,350
10,000	2.2	3.7	4.4	13.5	18.5	3,132
12,500	2.4	4.0	4.8	15.7	21.3	3,916
15,000	2.7	4.3	5.2	18.2	24.1	4,700
17,500	3.1	4.6	5.6	21.0	27.1	5,483
20,000	3.5	5.0	6.0	24.0	30.5	6,266
22,500	4.0	5.4	6.5	27.2	34.5	7,050
25,000	4.5	5.8	7.0	31.0	39.0	7,833
27,500	5.0	6.2	7.5	35.5	44.0	8,616
30,000	5.5	6.6	8.1	41.5	50.0	9,400
32,500	6.0	7.1	8.7	47.5	57.0	10,162
35,000	6.5	7.6	9.4	54.0	65.0	10,966
37,500	7.0	8.2	10.1	62.0	76.0	11,750
40,000	7.5	8.8	10.9	72.0	88.0	12,532
42,500	8.0	9.4	11.7	83.0	101.0	13,315
45,000	8.5	10.1	12.6	95.0	116.0	14,100
47,500	9.0	10.9	13.6	110.0	136.0	14,882
50,000	9.6	11.8	14.7	128.0	160.0	15,665
52,500	10.3	12.8	15.9	149.0	189.0	16,450
55,000	11.1	13.9	17.3	173.0	222.0	17,233
57,500	12.0	15.1	19.0	200.0	260.0	18,016
60,000	13.0	16.2	21.0	230.0	295.0	18,800
62,500	14.2	17.8	23.2	263.0	340.0	......
65,000	15.7	19.3	25.6	300.0	400.0	......
67,500	17.5	20.9	28.5	345.0	470.0	......
70,000	19.6	22.7	32.0	400.0	570.0	......
72,500	22.0	24.7	36.0	460.0	700.0	......
75,000	24.7	27.0	41.0	525.0	.....	......
77,500	27.7	30.0	47.0	600.0	.....	......
80,000	31.2	34.0	54.0	700.0	.....	......
82,500	35.2	39.0	62.0	.....	.....	......
85,000	39.7	44.0	70.0	.....	.....	......
87,500	44.7	50.0	80.0	.....	.....	......
90,000	50.7	57.0	92.0	.....	.....	......
92,500	58.0	68.0	109.0	.....	.....	......
95,000	67.0	75.0	131.0	.....	.....	......
97,500	78.0	86.0	150.0	.....	.....	......
100,000	91.0	100.0	193.0	.....	.....	......
102,500	108.0	121.0	245.0	.....	.....	......
105,000	137.0	159.0	283.0	.....	.....	......
107,500	190.0	227.0	345.0	.....	.....	......
110,000	290.0	325.0	410.0	.....	.....	......
112,500	398.0	430.0	500.0	.....	.....	......
115,000	500.0	550.0	600.0	.....	.....	......
117,500	600.0	650.0	700.0	.....	.....	......
120,000	700.0	750.0	800.0	.....	.....	......
122,500	800.0	850.0	.....	.....	.....	......
125,000	900.0	950.0	.....	.....	.....	......

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stance, in the coil referred to in illustrating the winding formula, there are 10,000 feet of No. 24 wire. This wire has a resistance of about 26 ohms per 1,000 feet, or a total of $26 \times 10 = 260$ ohms. The current this coil carries is equal to its circular mils divided by 1,000, or

$$\text{Current in coil} = \frac{\text{circular mils}}{1000} = 0.4 \text{ amperes, as found previously.}$$

The number of watts wasted are equal to:

$$\text{Ohms} \times \overline{\text{amperes}}^2 = 260 \times 0.4 \times 0.4 = 41.6 \text{ watts.}$$

Temperature Formula

The formula for calculating the temperature is as follows:

$$\text{Degrees F.} = \frac{100 \times \text{watts wasted}}{\text{sq. in. of radiating surface}}$$

The watts wasted in this case are approximately equal to 41, and if the square inches of radiating surface equal 100, the total rise of temperature in degrees F. would be

$$\text{Degrees F.} = \frac{100 \times 41}{100} = 41 \text{ degrees.}$$

This is not an excessive temperature rise and can be allowed.

The important point is the influence of an increase or decrease in the radiating surface upon the temperature of the coils. The amount of heat generated in a coil due to the resistance and current is about constant under ordinary circumstances. If the means by which this heat can escape are limited the temperature rises. On the other hand, if the radiating surface of the coil is large, the heat readily escapes and the temperature may remain constant. The problem is largely one in physics, where the heat is limited in quantity but the surface through which the heat escapes can be made larger or smaller, in which case the temperature drops or rises. If, for instance, the heat of a candle is concentrated at a point, that point would rise to a very high temperature. On the other hand, the heat, if imparted in its entirety to a large body of large radiating surface, would produce but a low temperature. The temperature of the body, therefore, is as much a question of the radiating surface, its character and extent, as of the amount of heat it has absorbed. In the case of a coil, the temperature should not rise much above 100 degrees F. If the coil develops a temperature of its own of 41 degrees and the surrounding air is at 60 degrees, then the total temperature would be 60 + 41 degrees or 101 degrees. If a coil of this kind is used in a place unduly heated, or, if it be put into operation in the tropics, then the temperature of the coil would become excessive. The surrounding atmosphere must be considered in the design of magnet coils, particularly when they constitute parts of dynamos in use in engine rooms, where the tempera

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ture is generally very high. The resistance of a winding is increased by its own heat, and this to some extent cuts down the flow of current.

The Magnetization Curve

The curve which shows the internal condition of the iron is called the magnetization curve. It is obtained by plotting a curve whose elements consist of ampere-turns per inch length and the number of lines of force they produce at each successive stage of magnetization. Such a curve is shown in Fig. 30. The value of such a curve in practical work is easily seen when the rise and direction of the curve is noted. The rapid rise of the curve with a very small magnetizing force shows how sensitive the iron is to magnetic influences when its reluctance is low and its permeability high. The result is a curve which rises with a slight inclination and then begins to bend. The bend of

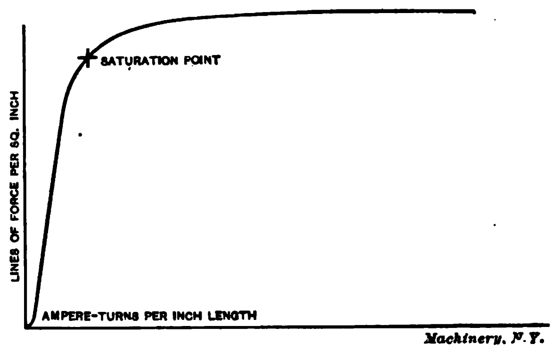

Fig. 30. The so-called Magnetization Curve

the curve indicates a distinct change in the permeability and consequently the reluctance of the iron. Following the curve for a short distance it is seen to bend with a greater and greater tendency to the horizontal plane, and, when reaching a horizontal direction, it begins to move constantly in this direction. At the critical point, where the bend originally begins, it will be noted that a given magnetizing force in ampere turns does not produce the effect it did before. In fact a little beyond this point it takes a comparatively great magnetizing force to produce a little additional magnetic field. This point is called the saturation point and is considered in practice the economical point at which to operate the iron. Beyond this point magnetism is obtained at too great an expense in wire and power. It is about 100,000 lines of force per square inch for wrought-iron and about 80,000 lines of force per square inch for mild steel, of which two metals the majority of dynamo cores are made.

In the curve the base line represents the ampere turns per inch length, and the vertical line, the magnetic lines per square inch of cross-section.

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CHAPTER III

ELECTROPLATING

Electrolysis is a department of electricity which treats of the effect of a current upon a chemical compound. By this is meant, that water, for instance, will succumb to the influence of electricity and be divided into its actual constituents, the two gases oxygen and hydrogen. The same is true of many other forms of chemical combinations. The action of a current is said to decompose the original body, and overcome in part or wholly the chemical affinity which exists between the elements of which it is composed. It is impossible to pay the proper attention to the effect of a current upon a solution within which are placed electrodes, unless the modern aspect of this branch of practical science is correctly presented. It must, therefore, be stated that the chemical theory previously accepted has been supplanted by the electro-chemical theory, and this theory is based upon the assumption that all elementary forms of matter possess charges of electricity.

Such a conclusion was necessary on account of the quality of *valency* possessed by atoms and molecules. By this is meant the peculiar choosing power, of oxygen, for instance, for two atoms of hydrogen, or of hydrogen for chlorine, etc. In other words, the elements, when in the form of atoms, have strange likes and dislikes which manifest themselves in the form of certain affinities for each other. Through these fixed affinities, the elements form chemical combinations, as in the case of water or acids. This choosing power inherent in the atoms, given by chemists the name of valency, is by the electro-chemist, attributed to varying charges of electricity. Thus the combination of oxygen and hydrogen is due to the electrical attraction of oxygen for hydrogen. On this basis, either one or the other must have a positive or negative charge. This charge, if powerful enough to form so intimate a combination, must be highly concentrated, because of the exceedingly small dimensions of the atoms and molecules themselves. In the case of water, it is a well-known fact that a current of electricity will decompose it into oxygen and hydrogen; and the curious phenomenon presenting itself under these circumstances will be that of the oxygen always clinging to the positive pole of the battery and the hydrogen to the negative. Placing two copper plates in a slightly acidulated solution, connected to a source of electricity, as shown in Fig. 31, will demonstrate this principle. The great mass of bubbles at the negative pole will serve to prove that twice as much hydrogen as oxygen is evolved. As water contains two atoms of hydrogen to one of oxygen, the quantity of the gases collected is in harmony with this proportion. As far as the practical application of this principle is concerned, the amount of gas evolved by this process can be cal-

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culated with mathematical certainty. Not only is this true, but if the two poles of a battery, which when employed for electrolytic work are called electrodes, are used in connection with a metal salt solution, such as water and sulphate of copper, a coating of copper will be deposited upon the negative electrode, the quantity of which also can be estimated beforehand with the greatest accuracy. The estimates made in the case of the gas refer to the quantity of it which will be evolved per unit of time. In the case of the copper the same holds true. In both cases certain values must be known:

1. The strength of the current in amperes.
2. The time in seconds during which the current flows.

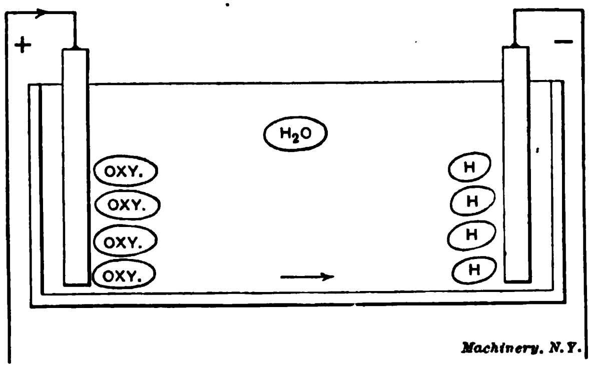

Fig. 31. Graphical Illustration of the Decomposition of Water into Oxygen and Hydrogen

The two battery terminals, called electrodes, are also named with reference to the poles they represent. The positive pole is called the *anode*, the negative pole the *cathode*.

The Grotthus Hypothesis

According to the hypothesis framed by Grotthus, when metals are being deposited, a curious transference of metal is taking place within the solution. Take, for instance, the case of copper being deposited from a solution of sulphate of copper, as indicated in Fig. 32. The chemical formula for copper sulphate is $CuSO_4$. This is divided up into two groups of atoms, one of which is positive and the other negative. The sub-divisions are those of the copper on the one hand, and the oxygen and sulphur on the other, as follows:

Copper ($= Cu$) moves toward the cathode.

Oxygen and sulphur ($= SO_4$) moves toward the anode.

According to this idea the electrolytic bath with the two electrodes immersed is traversed by two streams of atoms, one going to one pole, and the other to the other pole. But according to the Grotthus hypothesis, the solution of copper sulphate and the two streams of traveling atoms act in a very interesting manner toward each other. The solution of copper sulphate, for instance, permits a copper atom

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to leave the copper anode from which it has been electrically removed; it seizes it, but sends on its own atom of copper in place of the first to its destination, the cathode. The same process is carried out with respect to the oxygen-sulphur molecule. Thus the solution acts as an intermediary, whose strength will remain unaffected as long as the anode replenishes the lost atoms. An exchange goes on continually, with the result that the copper anode will gradually become lighter and its metallic equivalent will be found at the cathode, or on the objects placed there to receive it. These two oppositely moving streams of electrified particles have been designated streams of ions. If the

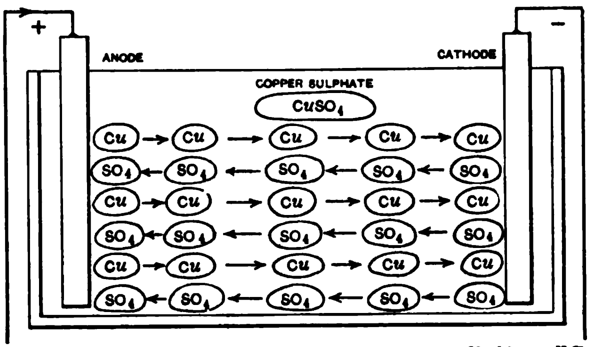

Fig. 32. The Process of Electroplating Graphically Illustrated

anode is of a neutral metal, for instance, or of carbon, then the solution used in this experiment will continually weaken.

The Electro-chemical Equivalent

The carriers of electricity being the ions, it may be questioned whether or not these ions carry equal quantities of electricity in the electrolytic experiment. To satisfactorily settle this question, a series of baths of silver solution, copper solution, etc., were prepared with electrodes of the proper character. The current sent into each was carefully measured, and the time during which this current flowed correctly gaged. It was found that in each case different results were obtained, although the current was preserved at a uniform value. The amount of silver deposited, for example, was different from that of copper, etc. In other words, a broad principle was discovered, a principle which showed that each particular metal was unique in this respect, that its ions or charged atoms were each the carriers of only a specified amount of electricity which was different with every different form of matter tested. The metals, particularly, displayed such differences that a table was made, called the table of electro-chemical equivalents, giving the exact weight of metal carried over by one ampere in a second. The table supplied herewith gives the name of the element, its atomic weight, its valency, its chemical equivalent, and its electro-chemical equivalent.

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The definition of the electro-chemical equivalent of a metal is as follows: The weight of the metal in grams carried over by one coulomb of electricity, that is, one ampere-second. On this basis, the weight of any metal, such as gold, silver, copper, lead, etc., carried over by a certain current in a certain time, can be readily ascertained by a simple calculation.

Calculating the Weight of Metal Deposited

In practical electroplating the judgment and experience of the plater is employed to its fullest extent in the determination of the amount of metal deposited on an object being plated. The weight of metal can,

TABLE OF ELECTRO-CHEMICAL EQUIVALENTS*

Elements	Atomic Weight	Valency	Chemical Equivalent	Electro-chemical Equivalent in Grams per Ampere-second
Electro-positive				
Hydrogen.............	1	1	1	0.000010384
Potassium.............	39.03	1	39.03	0.0004053
Sodium................	23	1	23	0.0002388
Gold..................	196.2	3	65.4	0.0006791
Silver................	107.67	1	107.67	0.0011181
Copper................	63.18	2	31.59	0.0003281
Mercury...............	199.8	2	99.9	0.0010374
Tin...................	117.8	4	29.45	0.0003058
Iron..................	55.9	3	18.64	0.0001935
Nickel................	58.6	2	29.3	0.0003043
Zinc..................	64.9	2	32.45	0.00033698
Lead..................	206.4	2	103.2	0.0010716
Electro-negative				
Oxygen................	15 96	2	7.98	0.00008286
Chlorine..............	35.37	1	35.37	0.0003673
Iodine................	126.54	1	126.54	0.0013140
Bromine...............	79.76	1	79.76	0.0008282
Nitrogen..............	14.01	3	4.67	0.00004849

* From S. P. Thompson's "Electricity and Magnetism."

however, be calculated from a knowledge of the time in seconds and the strength of the current in amperes, as follows:

Weight in grams = weight per second per ampere × current in amperes × time in seconds.

Reduced to symbols, the formula reads:

$$W = E \times C \times T$$

in which W = weight of metal deposited in grams,
C = current in amperes,
T = time in seconds,
E = the electro-chemical equivalent (that is, the weight of metal due to one ampere in one second, or one coulomb.)

To illustrate this formula, suppose a current of 100 amperes is employed for copper plating for 100 hours; then as the electro-chemical equivalent of copper is 0.0003281, as given in the accompanying table,

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the total weight of copper deposited would be 0.0003281 × 100 × 3600 × 100 = 11,812 grams = 11.8 kilograms = 26 pounds of copper.

In the above calculation the 3600 is the number of seconds in one hour. In Fig. 33 is shown how this calculation may be checked by a practical experiment.

Anions and Cathions

The atoms carried forward to the negative plate or cathode are called cathions and those passing the anode are called anions. The metals all move toward the cathode and are therefore termed cathions. The gas hydrogen also moves toward the cathode, and thus betrays the properties of a metal in an electrical sense. The anions are oxygen, chlorine and other elements moving toward the anode. This peculiar

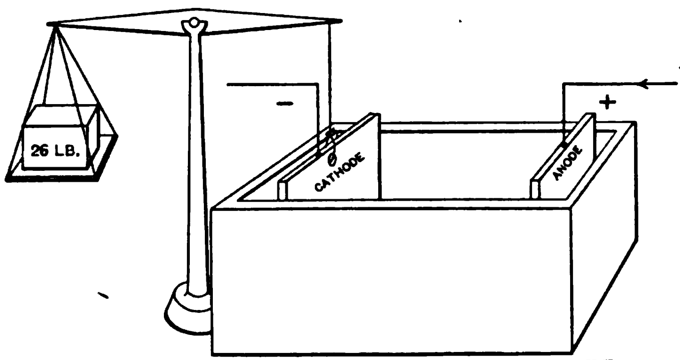

Fig. 33. Weighing the Copper Deposited

qualification has led to the conclusion that the natural charge possessed by atoms determines their position in the electrolytic bath as anions or cathions. The so-called anions, or ions with an attraction for the positive electrode, are regarded as negatively charged and are called "electro-negative." The cathions are positively charged, and called "electro-positive." This is the influence causing discrimination between the ions for either anode or cathode in electrolysis. When copper plating is done the Cu and SO_4, or copper and so-called sulphion, divide, the copper depositing on the cathode and the sulphion forming sulphuric acid by combining with hydrogen giving H_2SO_4, and thus intensifying the acidulation of the solution.

Electric Meters Based on Electrolysis

The idea of employing an electrolytic meter to determine from the increased weight of the electrode, the amount of current consumed by customers, is based entirely upon the electro-chemical equivalent. The original Edison Illuminating Company of New York used thousands of zinc sulphate meters, composed of two electrodes of zinc in a zinc sulphate solution, and receiving a shunted current from the customer's mains, as shown in Fig. 34. Each month the meters were re-

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placed by new ones and the added weight of the cathodes of the old ones carefully ascertained. The number of ampere-hours were thus determined on the basis of the electro-chemical equivalent. The final estimates were based upon the number of milligrams of zinc deposited.

The Deposition of Metals

The general process of depositing metals by means of electricity has developed into an industry represented by several distinct branches. Each of them is of importance in the commercial world and covers the following fields:

1. Electroplating.
2. Electrotyping.
3. Electro-metallurgy.

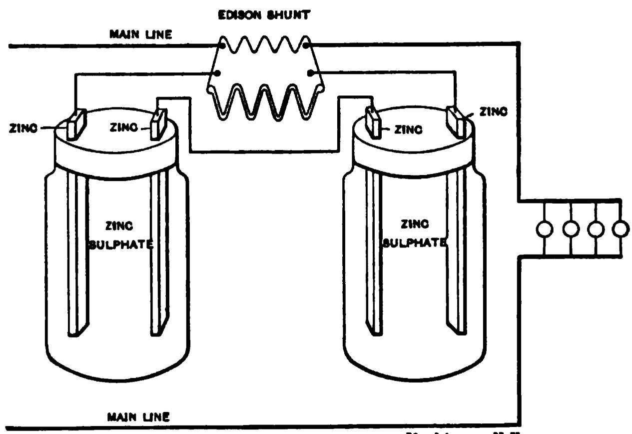

Fig. 34. The Principle of the Edison Meter for Electric Current based on the Deposition of Metal

Electroplating might be defined as a process in which a thin layer of metal, such as copper, nickel, gold or silver, is deposited from appropriate solutions called plating baths, upon some other metal, by means of electricity. The thickness of metal deposited is carefully gaged in the case of those metals that are termed precious, as gold and silver, and in consequence expressions are used such as triple or quadruple plate, etc.

The process of electrotyping is employed in all printing and publishing houses in connection with the duplicates of photo-engravings, used so extensively in this class of work. An electrotype is the exact duplicate, or as some term it, *fac-simile* of such master cuts or engravings as would be worn out by use in printing. These fac-similes are obtained by a plating process, although certain important preliminary processes are necessary. The name was probably derived from the practice of taking a wax impression of type and plating this impression with copper—hence the term electrotype.

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The refining of copper and other metals cannot be better done than by means of the electric current. Instead of delicate preparations being made for the deposit of a thin film of metal, as in electroplating and electrotyping, the current is utilized for the purpose of separating the pure metal from all impurities and depositing it in thick plates at the cathode. The anode would therefore be the crude ore, probably in the shape of a block, dipping of course in the correct solution. It is evident that this process does not differ essentially from either of the two previously mentioned, although the skill required in each case is of an entirely different character. The last process is associated with

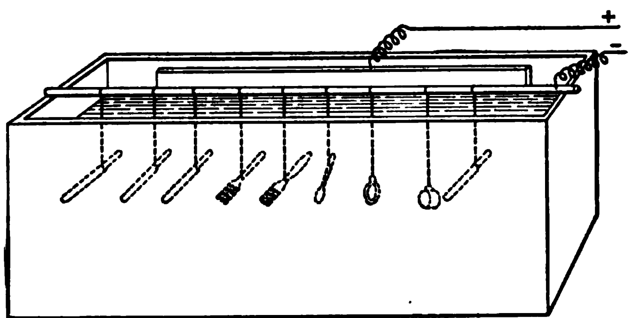

Fig. 35. Electro-plating of Small Articles

mining plants, particularly of copper ore, while both electrotyping and electroplating are fine arts.

Principles of Plating

The principles of plating embrace questions of correct current, electromotive force, solution, and certain preparatory processes. In other words, the current must not be too strong, and in addition the electromotive force must be capable of carrying the metal over. Cleanliness is an important item in this process, as the presence of oil or grease in any form will prevent the cathode from receiving its proper coating. The principal requirements of plating can therefore be best defined as follows:

1. Current of the proper strength per unit area of cathode.
2. Voltage suitable for the metal to be plated.
3. A solution electrolytically correct for the deposition of the metal.
4. A perfectly free surface at the cathode, with no traces of oil or grease.
5. A uniform current and electro-motive force.

In all arts, human skill, which is the direct result of extensive experience, is rarely if ever limited in its exercise by set rules. In electroplating, skill of this character has developed to a high point, and it may be considered as relating to two important features of the work as follows:

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1. Skill in the mixing and preparation of solutions.
2. Skill in the adjustment of the amperage and voltage employed.

The dynamo has displaced the battery in the art of plating and electrotyping, though small equipments can be purchased which are only operated by a few cells. A shunt-wound dynamo is generally employed the voltage of which can be varied from 10 or 12 volts to 3 or 5 by means of a rheostat in circuit with the field winding. By this means the pressure can be adjusted to suit the metal to be plated.

The plating solutions mostly used to-day are gold and silver, copper, nickel and brass solutions. The basis of these solutions are metallic salts manufactured with reference to the object in view and therefore called plating-salts.

Copper Plating Solution

Too great a density in the copper solution must be avoided, or the deposit will be brittle and crumbling and in addition very slow in making its appearance. A strong, tough deposit is obtained by a current of about 15 amperes per square foot of cathode surface. This solution may be made up either acid or alkaline. If acid, the deposit cannot be had upon iron or any other metal affected chemically by the acid. The following is the method for preparing an acid solution as given in Urquhart's "Electrotyping": "Prepare a saturated solution of copper sulphate by pouring hot water on the crystals of nearly the bulk required; add to this for each gallon of solution, a quart of water, and finally stir in for each gallon of solution four ounces of sulphuric acid. In the preparation of the solution it should be noted that by 'saturated' solution is signified that state of the liquid when it will not dissolve any additional salt. The crystals may be dissolved in a separate vessel and then poured into the depository trough, or the trough may be nearly filled with warm water and the crystals dissolved into it from a few muslin bags suspended in the liquid. The water used must be either distilled or filtered or at least the solution filtered when complete. This solution is well adapted for most purposes of the electrotyper, and has been tested repeatedly. It will deposit well upon metals or upon blackleaded moulds, and will be found to dissolve the anode freely when the current is passing. Some electrotypers use a large percentage of sulphuric acid, but this is seldom required except in very cold weather."

An alkaline copper solution suitable for deposits upon iron, zinc or pewter, quoted from the same source, is as follows: "Prepare a solution of copper sulphate, and also one of cyanide of potassium; add the latter to the former when a copious deposit of copper cyanide will take place. The liquid should be poured off and the residue washed, when it may be finally dissolved in a fresh solution of cyanide of potassium (two pounds to the gallon), to form the depositing liquid. As the cyanide of copper is not freely soluble in the potassium cyanide, it should be desolved to saturation. Free cyanide should be afterwards added to the extent of two ounces per gallon. This will promote rapid

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working, but there is also a stronger tendency to give off hydrogen at the cathode, the deposit at which may contain large quantities of gas. This solution works best at a temperature of 100 degrees F."

Nickel Solution

The double nickel salts are generally purchased in commercial form ready for solution according to these directions: "Dissolve the compound in hot water to saturation; afterwards dilute with water. The proportions are three-quarters of a pound of salts to one gallon of water. The solution should be neutral or nearly so, that is, neither acid nor alkaline. To ascertain this, test it with blue litmus paper; if the paper turns red increase the alkaline by adding ammonia sulphate. If red paper be turned blue, increase the acid by adding nickel sulphate until the mixture is as nearly as possible neutral. If there is a tendency to either side in working, it is better to have it alkaline."

Brass Solution

The method of making brass solution, the components of which are copper and zinc salts, is given by the following formula: "Dissolve in 1000 parts of water, 25 of copper sulphate, and 25 to 30 of sulphate of zinc; or 12½ of acetate of copper, and 12½ to 15 of fused chloride of zinc. Precipitate the mixture by means of 100 parts of carbonate of sodium dissolved in plenty of water and stir the mixture. Wash the precipitate several times by adding water to it, stirring and allowing the precipitate to subside, pouring the clear liquid away. Add to the washed precipitate a solution composed of 50 parts of bisulphide of sodium dissolved in 1000 parts of water, and while stirring, add a strong solution of ordinary cyanide of potassium until the precipitate is just all redesolved; then add three parts of free cyanide. This solution is used warm or hot. A current of about 12 volts must be employed, and an anode of brass. When the deposit is white it can be attributed to too strong a current, and if the deposit is red it is due to too weak a current. It is a simple matter to experiment with a small bath of solution, and a small anode and cathode, before attempting heavier work. A strong deposit of brass is a very handsome form of plating, which wears well and is not very difficult to obtain."

Slow Deposits and Unclean Anodes

The slow rate of deposit observed in plating is due to the employment of a weak current. This is frequently the case when an attempt is made to get a deposit upon a black lead surface. In this case the resistance is naturally very great, and in consequence, very little current passes. The remedy for this is a higher pressure, the use of which will hasten the process of deposition.

Absolute cleanliness is a guarantee of success in plating or electrotyping, and the reverse simply invites failure. Unclean anodes, on the surface of which dirt and oil or grease may be present, will greatly interfere with the work of plating. Some of this dirt, which is called

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by a certain philosopher, "matter in the wrong place," has been analyzed by a chemist and found to consist of particles of a great many different kinds of metals in the proportions in one particular instance of tin, 33; copper, 9; antimony, 9; arsenic, 7; silver, 4; sulphur, 2; and nickel, 2. A certain amount of organic matter also was found present, which militated against successful plating. Thorough cleansing is the effective means of disposing of this, such as washing in an alkaline bath.

Electrotypes of Coins or Medals

The surface of a coin or medal to be electrotyped is put through a preparatory process by first varnishing the back with beeswax or some rapidly drying insulating solution. The face to be plated must be cleaned thoroughly and then rubbed over with turpentine in which a little beeswax has been dissolved to avoid absolute adhesion between the electrotype and original. The use of small trays is recommended, with a connecting wire attached. These depositing trays hold the coin securely, and assure perfect contact between it and the cathode. When a dry, clean surface is first placed in the solution, the liquid may not take hold, due to a minute film of air on the surface. This must be removed by wetting the coin until the signs of this defect entirely disappear.

The intaglio or impression of a coin in wax is obtained by cleaning it thoroughly, and then dusting its surface very carefully with plumbago, leaving only a delicate film. It is then placed flat upon the wax plate of composition and pressure applied in the electrotyper's press. If a good impression has been obtained, the surface is dusted over with plumbago, by means of a soft camel's hair brush.

To obtain a conducting surface without the use of plumbago, the following formula is recommended: "Dissolve phosphorus in pure alcohol until a strong solution is obtained, and wash the mould with the mixture. A silver solution is prepared by dissolving nitrate of silver in aqueous ammonia to saturation. It is to be poured evenly over the surface of the mould, and allowed to float over it for a few minutes; the solution is poured off and the mould allowed to become partly dry, when it is again floated with the mixture. Spots that do not appear to take the solution readily must be wetted with it by means of a soft brush." A surface prepared in this manner is actually covered with a film of precipitated silver, highly conductive, and by some considered far superior to the old-established plumbago process.

The degree of saturation of the solution, and the strength of current, are always related to each other in a manner that can only be ascertained experimentally. Thus, if a saturated solution of copper is employed, the deposit is crystalline. If the solution is diluted with from two to four times its bulk of water, the metal is deposited in a malleable state, and a still further dilution will invite deposits of a granular character. A weak solution and a strong current will cause a

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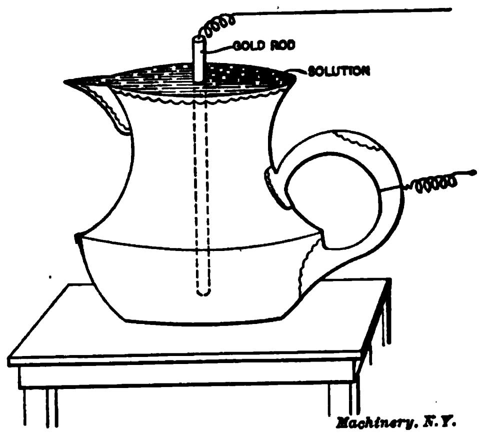
black, spongy coating to appear, associated with hydrogen bubbles. Under conditions which remain uniform, a definite deposit per second, per minute and per hour, is assured. An ordinary electrotype takes about five hours to become thick enough for service.

Pewter vessels are first copper-plated before undergoing the gilding or silvering process. The process of gold plating requires the use of the salts called the double cyanide of gold and potassium, and silver plating the double cyanide of silver and potassium. In plating with either of these solutions, the above mentioned precautions are necessary as regards absolute cleanliness, etc. When silver is being plated, too heavy a current, which forces the deposition, will give rise to a gray and crumbling coating. Bisulphide of carbon in a minute quantity, will make the deposited silver bright if introduced into the solu-



Machinery, N.Y.

Fig. 36. Method of Gilding the Inner Surface of a Pitcher

tion. In gold plating, generally performed in the insides of silver plated utensils, as shown in Fig. 36, the gold solution is poured into the vessel, and a gold anode suspended in the center from the positive pole of the dynamo, the negative being attached to the article itself.

Treatment of Plated Articles

The two courses of treatment to which the electroplater subjects articles undergoing plating may be classified as, first, that before plating for the purpose of securing electrical cleanliness, and second, that after plating in the nature of finishing. The following indicates this classification:

Before plating: Article may be washed in water, pickled in acid or scoured in lye.

After plating: Article may be scratched, buffed, polished or burnished.

Although cleanliness is above all the primary consideration, it is only obtained with respect to the surface of the metal by the use of

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vats of water, caustic soda and dilute acid. The surface of the article to undergo plating may have to be polished; it is then dipped in the hot lye solution to remove all traces of grease, then into the acid to remove any film of oxide present, and finally it is well washed in clean water.

When silver plating, one of the most prevalent platings in vogue, the copper surface is treated with mercury to secure a good foundation. A diluted solution of nitrate of mercury is applied, which forms a metallic precipitate suitable for the rapid and effective deposition of silver.

The scratching, buffing and polishing of plated articles are purely mechanical processes. Their object is to remove metallic projections, smooth the entire surface, and finally to give the high finish looked for in plated articles. The scratching is done by means of a wheel of brass wire projecting radially, which when rotating at a high speed acts as an effective scratch brush. The buffing is accomplished by the use of canvas wheels, composed of disks of canvas held at the center with the edges free. Buffing paste or powder is applied, and the marks of the scratching removed. The polishing is done by means of rouge or other fine polishing powders. The wheel may be of leather or walrus hide, by means of which a mirror-like surface is readily obtained.

Coloring Copper Surfaces

A copper plating can be rendered artistic by the following means: To obtain a rich brown color, the object must be dipped into a very diluted nitric acid solution, and gradually heated. By this process any shade of brown can be reached, which will possess great permanency. A fine black finish can be obtained by dipping the article into a weak solution of platinum chloride. This shade may be regulated by the strength of the solution and time of dipping.

Cause of Stripping or Peeling

One of the reasons why a dip into an acid bath is so necessary, or, as it is called, why pickling is employed, is to remove the oxide film which settles upon the surface of many metals and acts as a partial conductor to the current. Even when the conductivity of the surface is good, still there is no intimate contact between the coating and the cathode. Such a plating can easily "strip," that is, be peeled off. The removal of the oxide by polishing or by chemical means will insure a good deposit of metal. The pickling is always preceded by the lye solution, which, if hot, removes grease, and after washing, the acid solution follows.

Vats for Nickel Solution

The nickel solution is frequently poured, after being made up, into wooden vats lined with lead. The lead joints are not soldered but burnt together. Nickel can be deposited on copper, iron, brass and steel by a solution in which the crystals of the double sulphate of nickel and ammonium have been dissolved, according to the directions

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previously given. The vats are about 3 feet wide, 6 feet long and 30 inches deep, although the dimensions vary according to the work. Enameled vats are preferred by some platers because they possess strength, durability and insulating properties because of the coating. They are made of many sizes—from 1, 5, 10, 20 gallons, etc., up to 50 or 100 gallons capacity. All vats must have a rim of wood around the upper edge raised above the vat proper. The copper rods supporting the anodes and cathodes extend across, resting on this support.

Silver Salts and Solution

Effects of a most artistic nature are obtained by a proper handling of a silver bath in electro-plating. The silver salts may be considered as represented by the chloride, nitrate, cyanide, acetate, sulphide and oxide of silver. The cyanide of silver solution is used almost exclusively for silver plating and is made in the following manner: A solution of cyanide of potassium is carefully mixed, the preparation being made with well filtered or distilled water. A solution of nitrate of silver is also carefully prepared in the same way. The cyanide solution is then added slowly to the silver nitrate solution until a thick white precipitate is obtained at the bottom of the vessel. This white flocculent mass is washed with pure water several times until thoroughly cleansed. A new solution of cyanide of potassium is prepared and introduced gradually into the precipitate. The result of this operation will be the redissolving of the white mass and a new solution, to which is given the name "double cyanide of silver and potassium."

Successful silver plating can only be accomplished by patience and a strict adherence to the rules of cleanliness. Extreme cleanliness with respect to the solution makes it possible to use the same solution *for years*, if it is occasionally filtered or a little new cyanide added to replace or strengthen the old solution, and make up for the losses due to evaporation. Besides the question of cleanliness, attention must be paid to the current. A rough, gray or black silver plating results from the use of too much current.

Distance between Anode and Cathode

If an object suspended from the cathode has many projecting parts presenting an irregular surface to the anode, there should be considerable distance between the anode and cathode. The advantage of this is a more uniform distribution of the current and consequently a more uniform coating of silver. The edges are apt to take on a rough deposit even under the best of conditions. The larger surfaces will plate very smooth and even unless very much curved. If the object being plated is curved, it will be best to use an anode curved as far as possible in the same manner to obtain a fairly uniform series of paths through the liquid. In the plating of pitchers, sugar bowls, etc., the plating is only successful when special care is taken in this respect. The process of evenly plating statuettes or busts without destroying

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their contour is also a question of preserving equal current paths between them and the anode.

Iron Plating or Steel Facing

For the steel facing of electrotypes or other objects, a coating of pure iron may be deposited from a solution made up as follows: "To each gallon of water dissolve one pound of carbonate of ammonium, and dissolve iron into the solution by passing a strong current from an anode of iron until a deposit appears upon a clean copper cathode. A few ounces of carbonate of ammonium should be stirred into the bath once a week. The anode, which should be large in proportion to the work, must be cleaned occasionally." Another solution employed for the steel facing of plates, and given by Urquhart, is made up as follows: "Prepare a solution of sulphate of iron, and another of carbonate of ammonium. Add the latter to the former until the iron is precipitated; pour off the liquid portion and wash the precipitate. Take a bulk of sulphuric acid equal to the volume of the solution required, and dissolve the iron precipitate in it to saturation. If there should be any free acid it will retard the working; it is therefore usual to evaporate the solution a little." From either of these solutions good iron can be obtained by a current of from three to four volts. The anode is of iron, and the cathode of copper. According to Urquhart, the anode should be from five to eight times larger than the cathode to prevent the solution from becoming acid. It is also advisable to have the anode in the solution when not in use and to connect it by a wire to a cathode of platinum or copper to prevent the formation of acid and to keep the bath as dense as possible. The metal obtained is usually *as hard as steel*, but becomes soft and malleable after heating. It is very important to have a solution which yields a crystalline and very hard coating of iron. A coating obtained from a solution of sulphate of iron and chloride of ammonium yields an exceedingly hard deposit of the purest iron, and it is thus well suited to the coating of small and very fine electrotypes of steel engraved plates. All solutions made from sulphate of iron simply, are very troublesome and are constantly acted upon by the air, thus spoiling the solution. The salts in these solutions pass to a higher state of oxidation by absorption. Oxygen is rapidly absorbed and may appear in combination with the coating at the cathode. Charcoal iron is the purest to use as an anode and ordinary wrought-iron is the next best metal. If the solution is slightly heated, it will act much better in plating work. Acid and ammonium carbonate can be added occasionally to compensate for the oxidized salts. This must be so carefully done that the general composition of the bath is not changed. When attempted by beginners, this form of plating is full of holes, due to too much free acid in the solution and too heavy a current. Acidity can be held in check by the use of litmus paper for testing for this condition, and when it is found to be present, by neutralizing it. An oxidized solution may be deoxidized by passing a current through it

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for some hours between an iron anode and copper cathode. A little glycerine may serve to protect the solution from the effects of the air, but is rather objectionable.

Other Uses of Electricity

The application of electricity to produce electro-chemical changes is not limited to its use for the plating process alone. It is employed as the agency by means of which refining processes are carried out, germ laden masses of matter and infected water rendered innocuous, and new compounds produced. It is to be noted that electro-chemical changes are those in which a transposition of atoms occurs without any other outward signs than perhaps those due to bubbles of gas. On the other hand, the use of electricity for the manufacture of new in-

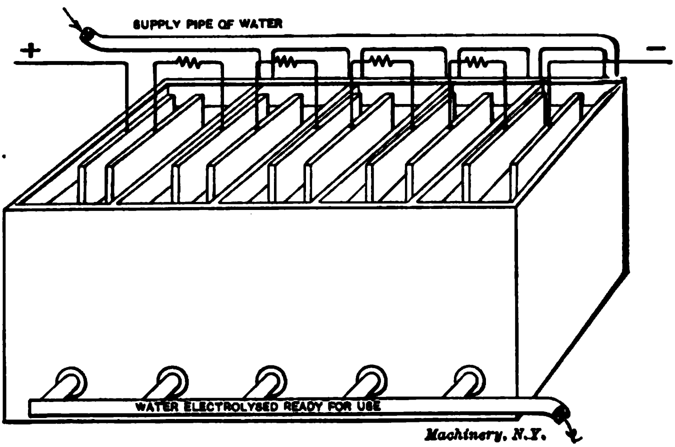

Fig. 37. Method of Purifying Water by Electricity used by a Large Packing Plant

dustrial products, such as aluminum, carborundum or calcium carbide, is attended by the development of intense heat.

Aluminum, the light, silvery looking metal, can only be cheaply obtained by means of electricity. It is distinctly an electrical product in a commercial sense, derived from the electric furnace by the melting of aluminum bearing ore. The heat of the furnace and, to some extent, electrolytic action, makes it possible to obtain the pure metal. The calcium carbide product, from which acetylene gas is obtained, is due to the coalition of lime and carbon in the electric furnace. Carborundum is also obtained in a similar manner by the conjunction of two foreign bodies fused by heat into an industrial product. Thus aluminum, the metal, calcium carbide, the gas producing chemical, and carborundum, a substitute for emery, and superior to it, are the first practical yield of the electric furnace. Of late the electric furnace has also found a distinct field in the metallurgy of iron. In the electric furnace, the high heat is due to the current passing through high resistances caused by imperfect contacts, and a rising temperature.

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Electro-sterilizing

It has been proposed on many occasions by scientists and inventors to sterilize the drinking water of large cities during plague periods by electricity. The germs of typhoid are peculiarly active in water. Other germs may be transmitted in a more or less malignant form through the medium of water. Hence, it is required as a measure of protection that the water be pure. To secure this end, it may be

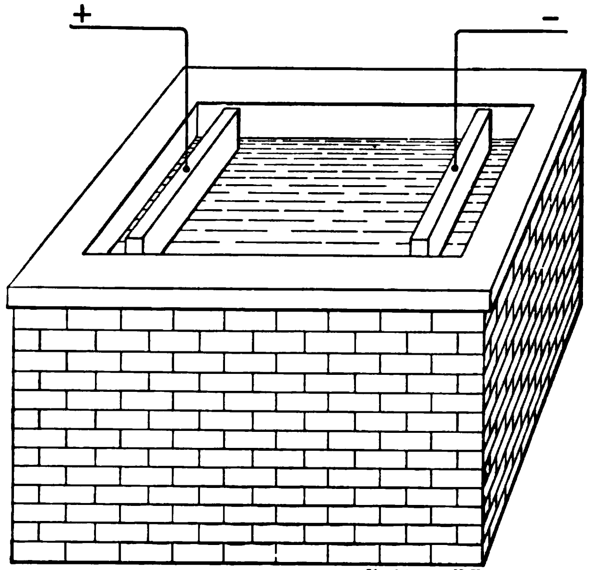

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Fig. 38. Destruction of Germs in Water by Means of Electricity

subjected to the effects of a current of electricity, the influence of which is destructive to animal life. That this method renders the water under suspicion free from active germs has been substantiated in many cases. Although not deemed a practical process on a large scale, electricity has been employed to destroy the virility of germ life in sewage or other refuse utilized in many instances for reclaiming ground. The process is called filling in, and was carried out extensively at Riker's Island near Hell Gate, where the refuse was thoroughly treated before used for filling.

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PRINCIPLES AND APPLICATIONS OF ELECTRICITY

PART III

DYNAMOS—MOTORS—ELECTRIC RAILWAYS

CONTENTS

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CHAPTER I

DYNAMOS

A dynamo is essentially a machine which generates electromotive force. The process of generating electromotive force, or E. M. F., as it is abbreviated, is by means of conductors moving in a magnetic field. When mechanical energy is applied to conductors which are passed through magnetic lines of force in a certain direction, an electromotive force is developed in them, which will be proportional to the speed with which they are moved, the number of conductors moved, and the strength of the magnetic field. The current produced in these turns or coils of wire will be proportional to the electromotive force generated and inversely proportional to the resistance. A dynamo, briefly, is a machine in which mechanical energy is transformed into electrical energy. A motor, in contradistinction, is a machine in

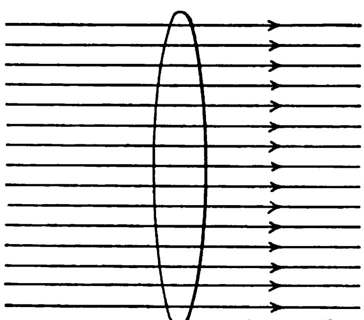

Fig. 1. Conductor Forming a Closed Circuit Moving in a Magnetic Field

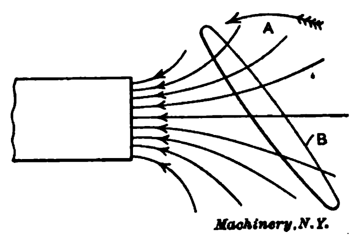

Fig. 2. Conductor Forming a Closed Circuit Moved so as to Cut the Lines of Force

which electrical energy is transformed into mechanical energy. Both the motor and dynamo are mutually convertible into each other by the mere fact of applying the power in a mechanical or an electrical form. This identity of these two machines or types of machines has been of the greatest importance in the fields of practical work, particularly in those of electric power transmission, transformation and distribution.

The subjects of electromagnetism and magnetic fields have been treated in MACHINERY's Reference Series No. 74, "Principles and Applications of Electricity, Part II," and the expression "lines of force" has also been defined in that book. If a wire or conductor forming a closed loop or circuit, as shown in Fig. 1, moves parallel to the direction of the lines of force in a magnetic field, so that no lines of force are cut by the loop, no current will flow in the conductor. If the loop *B* rotates as indicated by arrow *A* in Fig. 2, however, so that the lines

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of force are cut by the conductor, and so that the number of lines passing through the loop is constantly changing, either decreasing or increasing, then a current will be induced in the conductor. If the conductor merely cuts the lines of force, but in such a manner that the number of lines passing through the loop of the conductor remains constant, then an electromotive force will be produced, but no current will flow. Each half of the loop becomes impressed with an electromotive force of the same strength and polarity as the other half, and as the two oppose each other, no current will flow. The principles outlined may be summarized as follows:

The physical law upon which the generation of electromotive force is based requires the absence of uniformity in the motion of the conductor through a uniform field of magnetism. The conductor must move in such a manner that the number of lines of force it cuts are constantly changing in number. It other words, it may be stated that the generation of electromotive force depends upon a variation in the number of lines of force intercepting the conductor.

The direction of motion plays a great part in the direction of the current in a conductor exposed to the influence of lines of force. The conductor develops positive and negative electricity at ends which re-

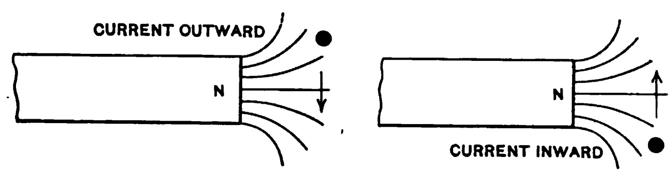

Fig. 3. Illustration showing Relation between Direction of Current and Direction of Motion of Conductor

verse their polarity when the direction of the motion is reversed. For instance, if a conductor is moved downward in front of the north pole of a magnet as shown to the left in Fig. 3, the current will tend to flow outward from the plane of the paper. The exact nature of the action which takes place and owing to which a closed electric circuit, when moved in a magnetic field, is able to absorb mechanical energy and give out its equivalent in electricity, even if known, would have no influence upon the practical application of this principle in electromagnetic machinery. Such knowledge would merely add another link to the chain which is being slowly forged in the physical laboratories of the world, connecting fact with fact and associating principle with principle for the purpose of showing the truth of great generalizations already made.

When a conductor is moved upward in front of the north pole of a magnet, electromotive force is also generated, but in this case the positive and negative poles of the conductor will be at such ends of the wire that the current with reference to the plane of the paper will tend to flow inward. Thus it is evident that an up and down motion of the conductor in front of the north pole would produce a series of electromotive forces which would be proportional to the number of

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movements per second, the strength of the magnetic field, and the length of the conductor in operation.

Direction of Field Around Inductive Wires

A wire producing electromotive force is acting as an inductor, because an electromotive force is being induced in it. The "blow" of a downward moving wire, upon the lines of force of a north pole produces a magnetic whirl around the wire, coincident with the generation of its electromotive force, and its polarity, or positive and negative ends. A reversal of the motion produces a reversal of the magnetic whirl around the wire, and of its electrical polarity and electromotive force.

If this experiment could be regarded as that of a stout metal rod striking a number of projecting flexible steel wires, it is easy to understand that a downward and upward blow would make them coil around the rod in opposite directions. There is this difference, however, that in the case of the metal rod, energy is consumed with each motion, while in the case of a moving conductor energy is consumed only in proportion to the current which flows. Consequently, if the conductor does not form part of a closed circuit, only electromotive force, but

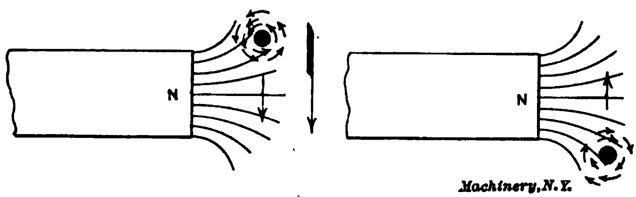

Fig. 4. Illustration showing Direction of Magnetic Whirl

no current results, and no energy is consumed. This fact is of importance because it shows that a dynamo on open circuit, although producing electromotive force, only takes from the engine enough power to overcome the requirements of friction at the bearings, commutator, etc.

The direction of the magnetic whirl around wires moving in a magnetic field, as shown in Fig. 4, is an indication of the direction of the current in them. The presence of this magnetic whirl, however, acts as a deterrent to the motion of the wire. It is this which constitutes in a mechanical sense the reaction. In fact, it is impossible to produce a current in a wire by its movement through a magnetic field without experiencing this drag on the conductor.

Elements of a Dynamo

If a north and south pole are now placed opposite to each other, as in Fig. 5, the magnetic lines have a free path across to the south pole. The number of the lines of force from the north pole have not changed because of the presence of the south pole; they simply continue on their way unchanged into the south pole. A conductor moving downward in front of the north pole produces a magnetic whirl

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which is in the opposite direction to the whirl produced around the conductor moving upward in front of the south pole. This means that the current issuing from the first wire will flow in an opposite direction to that issuing from the second wire. If they were connected at their ends as in Fig. 6, and then rotated around an axis instead of being individually moved up and down in the magnetic field, practically the same movement would be accomplished by circular motion. In a dynamo this idea is followed out, and the result is that the conductors constantly produce a reversing or alternating current. Certain prac-

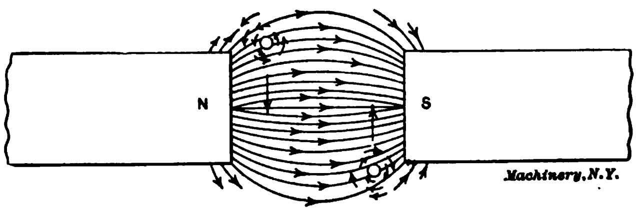

Fig. 5. Conductors Moving between the Poles of a Magnet

tical details require attention in this respect in order to outline the conditions resulting from such an arrangement in actual practice.

Alternating and Direct Currents

There are two kinds of dynamos or generators in use for generating current for electric lighting and electric power. They are called alternating and continuous (or direct) current machines. The difference between one class of machines and the other is entirely due to the fact that in

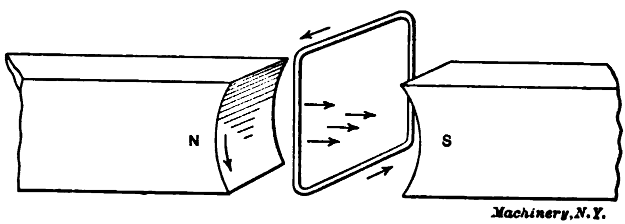

Fig. 6. The Elementary Principle of the Dynamo

the first class, that for producing alternating current, the electrical energy is permitted to issue in the same manner as it is produced or generated. In the other class, the direct current generators, the alternations or reversals of current are rectified by means of a device called a commutator. This device is the means of causing all the impulses of current to be divided up into those which leave at the positive and those which enter at the negative pole. In other words, it sends out all positive currents from one pole of a dynamo and receives all negative at the other. The difference, therefore, between so-called alternating and direct current machines is not due to the fact that they generate different currents, because both develop alternating currents, but is due to the fact that the direct current machines have a commutator or rectifier and the alternating current machines have not.

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The Calculation of Electromotive Force

The meaning of the word current with respect to electricity has no significance unless associated with a conception of the electromotive force. As already stated, there are three elements necessary for the development of electromotive force, these being lines of force, conductors, and motion. Cases arise in connection with alternating and direct currents where motion is not apparent. Yet it is there; if not visible, it must be the motion of the magnetic field. If a conductor is held stationary, and a magnet moved so that its lines of force cut the conductor, a parallel case is presented; but even in this instance the magnet is moved, whereas under particular conditions only the magnetic field itself moves.

Electromotive force is measured in volts. One volt is equal to the cutting of one hundred million lines of force by one conductor in one second. The conclusions to be drawn from this statement are obvious. If one hundred million lines of force must be cut by one conductor to generate one volt, then one-half as many cut by two conductors in one second or one-quarter as many cut by four conductors in one second will generate one volt, etc. From this statement is drawn the conclusion necessary for deducing a very simple formula, by means of which the electromotive force of a dynamo is calculated before construction takes place as follows:

E.M.F. in volts = (number of lines of force × number of conductors × revolutions of the wire per second) ÷ one hundred millions. Transcribing this formula into symbols for convenience:

$$\text{E.M.F.} = \frac{F \times S \times r}{100{,}000{,}000}$$

where F = number of lines of force,
S = number of conductors,
r = revolutions per second.

To illustrate the application of this formula let $F = 5{,}000{,}000$; $S = 100$; and $r = 20$, which represents 1200 revolutions per minute. The volts would equal $5{,}000{,}000 \times 100 \times 20$ divided by 100,000,000, which equals 100 volts.

The Magnets of a Dynamo

Before going further, it will be necessary to define the meaning of the expressions "armature" and "field magnets". The armature of a dynamo, in general, is that portion of the machine which is revolved between the poles of the magnets of the dynamo. These magnets are usually called field magnets. The armature consists of coils of insulated wire and an iron armature core, on or around which the coils are wound. The magnets are electromagnets, energized through coils of wire wound around their core, an electric current, called the field current, being sent through the coils of the magnets for this purpose.

The three important parts of a continuous current dynamo are the armature, commutator and field magnets. The commutator is not required for an alternator, or machine generating alternating current.

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The conductors wound and firmly secured around the armature core have terminals ending in the commutator. Both commutator and armature are mounted on one shaft, by means of which the conductors are rotated in the magnetic field provided by the magnets. In some dynamos the coils of the magnets act almost directly on the armature, the magnetism passing through the end of the core which is curved to conform to the cylindrical shape of the armature and at the same time permitting it to rotate freely. In other dynamos the core is attached to a pole piece which may be of the same metal as the magnet core. If this is not the case, the core is generally of wrought iron and the pole pieces of cast iron. The ultimate purpose of the magnet winding is to force a certain amount of magnetism across from one pole piece to another. In order to get across, the magnetism must pass through the air-gap existing between one pole piece and the armature core and then again from the armature core through the air-gap back to the other pole. It is of the greatest importance in a continuous current dynamo for incandescent lighting, that the magnetism, speed and armature turns co-operate so advantageously that the electromotive force produced by the machine for outside use remains unchanged.

Construction of the Armature

The armature core is not composed of a solid cylinder of iron; on the contrary, it consists of a great number of thin sheets of wrought-iron bolted together to give mechanical rigidity. If the armature was not composed of laminæ in this manner, it would act as a solid conductor moving in a powerful magnetic field and in consequence would generate a strong current. The effect of this current would be the generation of an intense heat and a great waste of energy. Foucault was the first to suggest and to try the effect of subdividing the armature core at right angles to the lines of force in which it rotated. This practice is now followed out universally and is termed "lamination." The sheets of iron are stamped, and in some cases thin paper is placed between the laminæ, although experience has shown that a coating of varnish or the oxide of the iron itself is all that is necessary to prevent electrical contact between plate and plate. Originally the conductors of direct current dynamos were wound on the outside of the core and held in place by bands of wire, but the armature cores are now slotted and the wires are wound in these slots and held either by means of bands of brass wire surrounding the armature or by fiber strips slipping into and held by these slots, over the wire they contain.

Armature cores may be either simple cylinders, which have the wire wound completely around them, or they may be hollow inside and represent what are called ring and disk armatures. Both of these last named armature cores have the wire threaded through them instead of around from one side to the other across the ends. The cylindrical core is called "drum" armature and the ring "gramme" armature. The disk armature is sometimes called "the flat ring," to distinguish it from the ring, which is longer axially. Ring armatures are mounted on

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the shaft by means of spiders to secure them against slippage and vibration. The question of speed must be carefully considered in the construction of armatures and their mountings. The most solid type of armature and one largely in vogue at present is the drum. In the ring armature the conductors are wound around the ring; the consequence of this is that the inside wires are not generating electromotive force. In the drum armature the end wires crossing both bases of the cylinder are inactive and do not generate electromotive force.

Types of Direct-current Dynamo Windings

The manner in which a dynamo begins to generate electromotive force is best understood by referring to the method of winding the

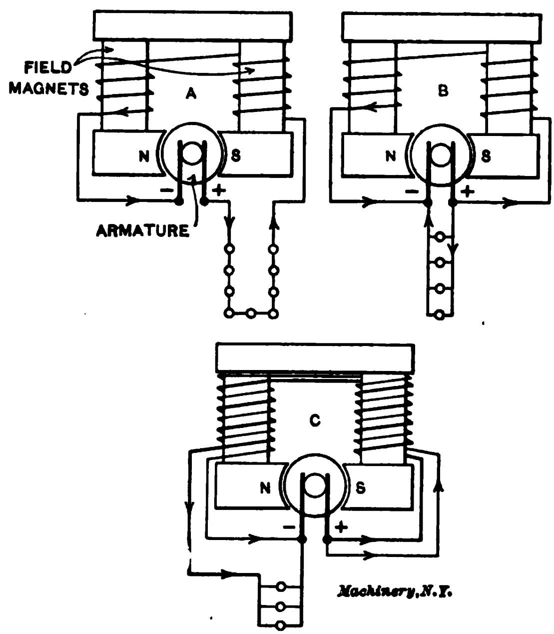

Fig. 7. Types of Dynamo Windings

fields and connecting them to the armature. There are three general types of dynamos, bearing the names of series, shunt and compound, according to their windings and connections. In the series wound dynamo, a diagram of which is shown at *A* in Fig. 7, the current generated in the armature flows out into the outside circuit, generally of lights, and returns to the dynamo through the winding of the fields. The circuit is therefore completed by the armature, lights and field being *in series* with each other. The shunt dynamo, as shown at *B*, operates differently, the current from the armature passing through the outside circuit and returning to the armature, the field taking its current independently from the armature terminals or *in shunt*. The

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compound wound dynamo, as shown at *C* in Fig. 7, represents a combination of these two windings. It has a shunt field which takes its current from the armature terminals and an auxiliary series winding through which all the current of the machine passes in series with the entire outside circuit.

Generating Electromotive Force

When a series, shunt or compound wound dynamo is set into operation, the action by which electromotive force is developed and a current thrown into circulation does not take place instantaneously. The process is a self-regenerative one and depends in the first stage of its growth upon the presence of *residual magnetism* in the iron core and pole pieces of the machine. The least trace of magnetism in the pole pieces will enable the armature to generate a little electromotive force. This electromotive force will send a minute current through the magnet windings, whether it be a shunt or series wound machine. The effect of this current is to produce a little more magnetism in the magnets and thus supply more lines of force to the armature to cut for the generation of more electromotive force. With more electromotive force, a stronger current circulates through the magnet windings, continually augmented in strength by the reinforcements of electromotive force from the armature, until a climax of development is reached when the dynamo is delivering its normal pressure. The process cannot go on indefinitely because the magnets will not produce more than their proper quota of lines of force, and neither the speed nor conductors can change in numerical value. Therefore, when the iron becomes saturated and the speed and conductors remain unchanged, the electromotive force will not vary. It must be understood, however, that if any one of these three items undergo a change, a corresponding change will be experienced in the development of electromotive force. A dynamo which can increase or decrease its magnetic field will proportionately affect the voltage produced. If by any means, the speed remaining the same, the number of the conductors can be controlled in a dynamo, in like manner the electromotive force will increase or diminish.

The Alternator

The alternating current dynamo generates a current which cannot be used for exciting a magnetic field in the same manner as a current produced by a direct current machine. The electrical energy of an alternator consists of a rapidly reversing electromotive force and current. The positive and negative poles of the dynamo are constantly reversing, and the number of alternations per second depend upon the speed of the armature and the number of magnetic poles the conductors move past per second. The magnetic field is obtained from the current of a small continuous current dynamo called the "exciter." This machine may be permanently attached to the alternator, or it may be merely belted to the shaft supplying both with power. Its entire function is to supply current to the field magnets of the alternator, which current,

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it must be distinctly understood, is not always obtained in this manner. It is sometimes obtained from an auxiliary or independent winding on the alternator armature which is connected to a commutator and thus makes the alternator self-exciting. The general plan, however, is to keep the exciter separate in the manner described. An alternator generally consists of four or more poles or magnets. A few figures are given in the following table showing how the reversals of current are due to the number of poles and the speed:

Revolutions per Second	Pairs of Poles	Complete Reversals of Current per Second
10	1	10
15	1	15
20	1	20
25	1	25
30	1	30
10	2	20
15	2	30
20	2	40
25	2	50
30	2	60
10	4	40
15	4	60
20	4	80
25	4	100
30	4	120

The idea represented here is as follows: A conductor moving past a north pole develops a current opposite in direction to that developed when moving past a south pole. A complete cycle only occurs when the wire sweeps past a north and south pole in succession. In this case the wire generates an electromotive force, which rises from zero to its full value, and drops again to nothing just the instant before it passes under the opposite pole. When passing under the opposite pole the process is repeated in a reversed direction and when completed the wire is about to enter upon the same cycle again. This is therefore called a complete reversal of current and is due to a conductor passing *one pair of poles*. If it passes a pair of poles 10, 15, 20, 25 or 30 times a second, just so many times will a complete reversal of current take place. Multiplying the revolutions per second by the number of pairs of poles will give the reversals, or as it is generally called, the frequency of the current.

Waves of Electromotive Force

The function of the commutator and its relation to the impulses of electromotive force generated in the armature can be best understood by reference to what is called "a wave of electromotive force." In any dynamo, whether it be a bipolar or multipolar, every conductor passing the poles has an electromotive force generated in it which is in strict proportion to the lines of force it cuts. If the electromotive force of a conductor passing in front of a north pole is estimated in

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a series of positions, the product of the number of lines of force by the speed of the conductor will give the amount of electromotive force developed. Suppose the electromotive force is measured while the conductor is rapidly passing through these positions, then, at each point, the electromotive force will differ, provided the rate of motion is uniform, because the lines of force are so distributed that in their case no uniformity exists. If use is made of such data as can be obtained in this manner to graphically represent the entire process, as shown in Fig. 8, then, by letting the length of vertical lines be a measure of the electromotive force developed at each instant, and a base line be proportioned to the time during which these various electromotive forces are produced, a curve can be drawn through the extremities of the vertical lines which will adequately picture the rise, full growth, and fall of the electromotive force. As the wire moves on to pass beneath a south pole, the generating process is repeated and the result in consequence is a wave of electromotive force in one direction under a north pole and a wave of electromotive force in the opposite direction under a south pole. The more abruptly these waves

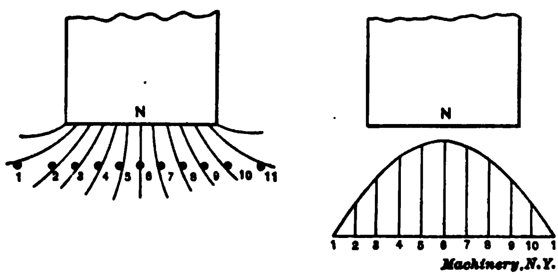

Fig. 8. Graphical Illustration of the Rise and Fall of Electromotive Force in a Conductor

are produced, and the greater the electromotive force they represent the more difficult it is to obtain what is commonly called a continuous current. If heavy impulses, due to a great many turns acting cooperatively, are rectified by means of a commutator, which would, under the circumstances, consist of comparatively few segments, then such a current would represent a series of direct pulsations. The current is direct, but not, in the strict sense of the word, continuous. It is like the stream which issues from a powerful force pump without a pressure chamber—the stream is all directed one way, but occurs in increasing and diminishing spurts. If, on the other hand, the armature conductors are so arranged that only a few are connected to each commutator segment, then there would be many commutator segments required. The result of this would be to bring the current down to a gentle ripple, approximating uniformity. It would still pulsate, but with small pulsations, which is the object sought by designers when laying out continuous current machines for incandescent lighting. A graphical illustration of the statements just made is shown in Fig. 9.

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It is needless to state that if an armature core was wound with 1000 turns of wire, by means of which, when revolving at 1000 revolutions per minute in a magnetic field, 100 volts were generated, a commutator consisting of only two segments would cause destructive sparking. If, however, the commutator segments were increased to 4, 6, 12, or in fact to something like 50, and the 1000 conductors were divided up between them, then the sparking would be very much reduced. In other words, the commutator segments, and the volts produced by the armature conductors, must be proportioned with regard to two things: First, the uniformity of the current; second, the sparking at the dynamo brushes.

Heavy pulsating currents are employed for high tension arc lighting. Direct currents of a uniform character are employed for low tension incandescent lighting. In Fig. 9 the change of the curve from a

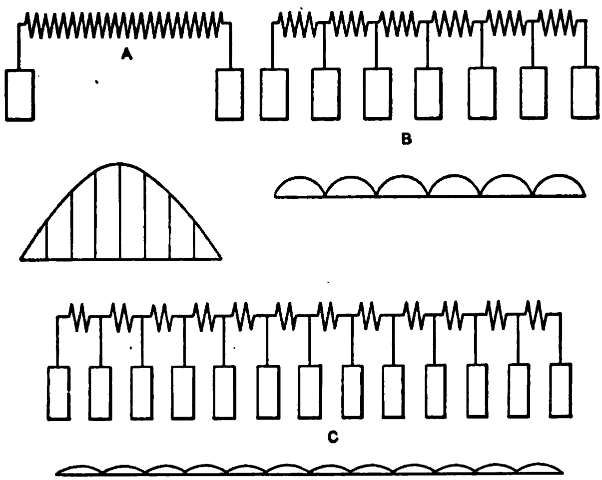

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Fig. 9. Graphical Illustration of the Influence of the Commutator Construction on the Current Pulsations

heavy impulse to a ripple-like flow is due to the use of a greater number of commutator segments. Carrying out this idea to its practical limitations would give a current so uniform in character that it would compare with the discharge from a storage battery through a fixed resistance.

Alternating Current Dynamos

There are several varieties of alternating current dynamos, distinguished from each other by an interesting peculiarity called "phase." To enumerate, there is the single phase, two phase, and three phase dynamo. The meaning of phase may be readily understood with reference to the character of the currents they individually produce; but it is necessary to represent these differences partly by a diagram.

A wire on the armature of an alternator rotates past a series of

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poles of different polarities. It passes a north pole, then a south pole, then a north pole, and so on, as it continues its rotations. (See Fig. 10.) Every north pole it passes produces an impulse in the same direction; that is, all one way, and every south pole it passes produces an impulse in the opposite direction. Thus, the impulses of current due to the north poles are all in one direction and the impulses of current due to the south poles are all in the opposite direction. This idea is represented by a series of curves placed over or under a base-line, as shown at *B* in Fig. 11. All the curves or waves over the line can be regarded as impulses due to north poles, and those under the line as impulses due to south poles. Therefore a diagram of this character adequately represents the increase and decrease of the electromotive force as the conductor sweeps past a north pole, the par-

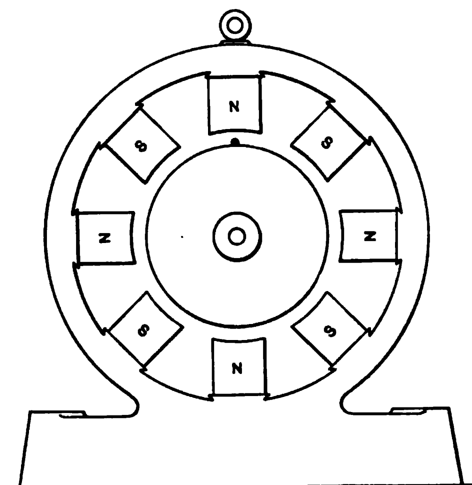

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Fig. 10. Elements of a Dynamo

ticular instant at which no electromotive force is generated just as the conductor has emerged from the lines of force of the north pole and is about to enter those of the south pole, and the rise and fall of the electromotive force due to the south pole with a return to practically the same conditions as the cycle is about to be repeated. Each pole is capable of producing one wave of electromotive force in a conductor, and in consequence it is customary to depict this process of electromotive force development by a curve as described. The name given to a curve of this character by mathematicians, and so called by electricians, is "the sine wave."

A great many impulses occur in the winding on the armature of an alternator every time the conductors pass each pole. It has been necessary to devise a winding which would throw all similarly moving currents in one direction and thus avoid opposition between them. This is readily done by laying flat coils on the armature, each around a pro-

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jecting core, and connecting their ends together, the outside terminals of adjacent coils and the inside terminals of those next adjacent, and so on, as shown in Fig. 12, until the two final ends are connected respectively to collector rings (see Fig. 12 and upper view *A* in Fig. 11), from which by means of brushes an impulse is collected as the coils on the armature pass a pole piece.

Two and Three Phases

If another current follows after the first impulse of an alternating current, but not so slowly that it differs in any respect from the first except in being an instant behind it, there are what are called two phases acting in the circuit. If three distinct currents follow each other in this manner, each an instant behind the other, yet not so far behind that the three currents are not at some stage of growth or diminution at the same moment, there are three phases of current in the circuit or it represents a three-phase current.

Phases of this kind are produced in a very simple manner. The ar-

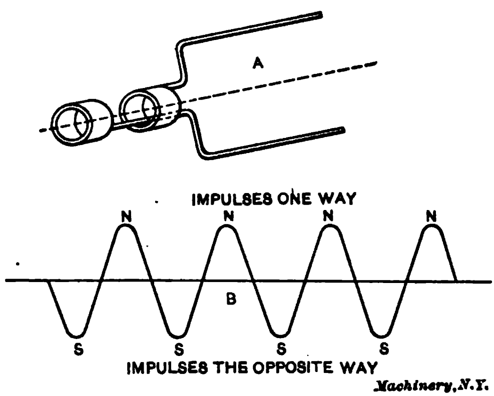

Fig. 11. Collector Rings and Graphical Illustration of Characteristics of Alternating Currents

mature conductors are connected in such a way that in the case of a two or three-phase dynamo practically two or three distinct windings are in operation at once. In one winding the armature conductors, for instance, are one-third of the distance across a pole piece before the second winding is in operation. By this means the beginning of an impulse is one phase, which follows all the laws of an ordinary alternating current. The phase beginning when the first conductors have already been developing electromotive force along one-third of the arc of the pole piece also rises to its full value and acts like the first phase. A third can follow in the same manner if the conductors are properly arranged and connected to individual collector rings. Thus, instead of only one—two, three or more phases or currents can be developed by this method, each distinct from the other, an instant behind it, and serviceable for electric lighting and power transmission. Rotary converters found in power houses and sub-stations, and nearly all self-

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starting alternating current motors, are actuated by multiphase currents of either of two or three phases.

Hence it will be seen that by adding further windings, in intermediate positions relative to the first or original winding, any number of alternating currents may be generated, each differing from the other in phase, that is, being a very small fraction of a second behind it. For each phase two conductors are necessary. Hence, it is necessary to limit the number of phases, so that undue multiplication of conductors is avoided.

For two-phase currents, for example, four conductors are necessary, except in cases when a single return conductor is used, when three conductors are sufficient. For three-phase currents six conductors would be required, except for the condition that the current flowing in

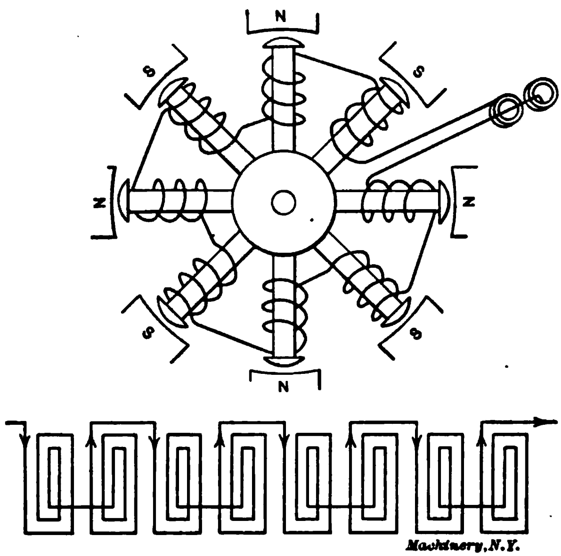

Fig. 12. Principle of Winding an Alternating Current Dynamo

one phase is always equal and opposite to the sum of the currents in the other two phases. Hence the return wire for each phase may be omitted, and three conductors only need be used.

Hysteresis

The iron core of the armature is magnetized first one way and then another, whether it belongs to an alternator or a direct current dynamo. The effect of this is to consume power which manifests itself as heat. This phenomenon always appears when iron is magnetized and demagnetized. The reason why power is consumed is as follows: When a bar of iron is magnetized by means of a coil carrying a current, and the ampere turns or magneto-motive force is great enough to saturate it, the molecules of iron assume a certain polarized posi-

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tion. If an equal and opposite magneto-motive force is applied by means of the coil, the iron *will not* of itself return to its normal condition; it will require extra magnetizing force to accomplish this, and if the process is continued until the iron is magnetized as highly in the opposite direction (with reverse poles) as before, and then brought back to where it started from, it will be found that a considerable amount of power has been absorbed. A process of this kind is called a cycle of magnetization, and is graphically illustrated in Fig. 13. Although the process merely consists of the magnetization and reverse magnetization of iron with a final return to the starting point, yet each instance presents an opportunity for power to be absorbed, which increases as the degree of magnetism to which the iron is subjected increases, and also with the rapidity and frequency of the cycles. If a cubic foot of soft iron is put through such a process, it will, according to a noted authority, when magnetized up to 60,000 lines of force per square inch, absorb 10 foot-pounds of energy. If the process is carried on at the rate of 100 times a second, 1000 foot-pounds of energy are absorbed. It is easy to estimate that each minute would represent a power consumption of 60,000 foot-pounds or nearly 2 horsepower, at this rate of change. All armature cores, therefore, must be calculated with respect to such a dissipation of energy, and it is necessary to obtain figures which will enable such calculations to be carried out. A formula has been deduced by Steinmetz, upon which all calculations of hysteresis (the name given to this property of iron) are based.

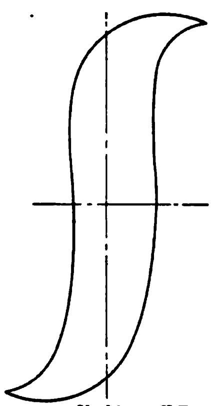

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Fig. 13. Hysteresis Curve

The Steinmetz Formula for Hysteresis

The Steinmetz formula requires an understanding of quantities with fractional exponents, and the use of logarithms.* In the formula a constant is multiplied by the lines of force per square centimeter, the latter value being raised to the 1.6th power; this gives the power consumed in *ergs* (see definition in the following) in one magnetic cycle for one cubic centimeter of iron, or:

Power consumed $= 0.002 \times$ (lines of force per square centimeter) $^{1.6}$,

in which 0.002 is called the hysteretic constant, and is an average of the actual constant for different classes of iron. The actual constant is for:

Wrought-iron—hysteretic constant 0.0017
Steel—hysteretic constant 0.0025

The above formula, reduced to symbols, would appear as follows for one cubic centimeter of iron:

$$W = 0.002\,B^{1.6},$$

where W = power consumed in ergs in one magnetic cycle,

B = lines of force per square centimeter.

* See MACHINERY'S Reference Series No. 53, "The Use of Logarithms."

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The value of an erg is best understood by reference to a foot-pound. A foot-pound equals 13,350,000 ergs. In the following table, in which the lines of force per square centimeter and per square inch are given, the calculations by the Steinmetz formula are carried out for iron subjected to a series of increasing magnetizations:

FLEMING'S TABLE

Lines of Force per sq. cm.	Lines of Force per sq. inch	Ergs per cubic cm.
1,000	6,250	126
2,000	12,500	383
3,000	18,750	732
4,000	25,000	1,160
5,000	31,250	1,658
6,000	37,500	2,222
7,000	43,750	2,840
8,000	50,000	3,516
9,000	56,250	4,244
10,000	62,500	5,022

When using this table, the number of complete reversals of magnetism per second must be multiplied by the waste of power per cycle. For instance, if the frequency of an alternating current is 120 per second, a well known commercial rate for lighting circuits, the power wasted at 5000 lines of force per square centimeter, or 31,250 per square inch, would be 3.22 foot-pounds for a cubic foot of iron per complete reversal. For 120 complete reversals the power wasted would be $120 \times 3.22 = 386$ foot-pounds.

In reference to the equivalent of an erg in foot-pounds, it may be stated that one pound equals 445,000 dynes. A dyne is the force required to impart to a gram a velocity of 1 centimeter per second. An erg is *the work* done in moving a body a distance of 1 centimeter

POWER WASTED PER CUBIC FOOT OF IRON AT 120 REVERSALS PER SECOND

Lines of Force per Square Inch	Lines of Force per Sq. cm.	Ergs per Cubic cm.	Foot-pounds per Cubic Foot
6,250	1,000	120 x 126	29.82
12,500	2,000	" " 388	89.18
18,750	3,000	" " 732	178.00
25,000	4,000	" " 1160	270.00
31,250	5,000	" " 1658	386.00
37,500	6,000	" " 2222	517.06
43,750	7,000	" " 2840	661.00
50,000	8,000	" " 3516	818.17
56,250	9,000	" " 4244	987.60
62,500	10,000	" " 5022	1168.60

against a force of 1 dyne. If a gram is moved against gravity a distance of 1 centimeter in 1 second, 981 ergs of work are done. A pound is equal to 453.59 grams, and the force of gravity equals 981 dynes per gram; hence, $453.59 \times 981 = 445,000$ dynes or 1 pound. If 1 pound

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is lifted 1 foot, it means a force of 445,000 dynes operating over a distance of 30 centimeters, the basis of estimate being 0.4 inch per centimeter and therefore 30 centimeters per foot. This calculation gives 445,000 × 30 = 13,350,000 ergs = 1 foot-pound. If the last column of figures in the Fleming table, which gives the energy wasted in ergs, is given in the English system for 1 cubic foot of iron magnetized and demagnetized at the rate of 120 times a second, the result will be as given in the lower table on page 18.

For armature cores this last table is very useful, as well as in those cases where the use of magnets on alternating current circuits are proposed. In alternating current work in general, whether single, two or three phase, dynamos, motors and transformers are of necessity in almost constant use; and these machines call for a careful application of the principles outlined so far as hysteresis is concerned, otherwise the internal development of heat within the iron would not only waste power, but rapidly put a stop to the operation of such machines altogether.

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CHAPTER II

THE ELECTRIC MOTOR

An electric motor is a machine in which electrical energy is transformed into mechanical energy. This is the reverse of the dynamo, which is a machine in which mechanical energy is transformed into electrical energy. To transform electrical energy into mechanical energy the medium of the electro-magnet comes into play.

The construction of the motor is practically the same as that of the dynamo, and a dynamo is capable of running as a motor if supplied with current through its armature and magnets. The principle upon which the action of the electric motor is based is that a conductor carrying an electric current tends to move if it is placed in a magnetic field. The tendency is for the conductor to move into a position where the lines of force passing through its loops become parallel to, or coincide with the lines of force in the field of the magnets. Hence, a motor, like a dynamo, consists of a magnetic field, produced by field magnets, and conductors wound on an armature core, and so arranged that they can move when acted upon by the field. This is the simple theory of action and construction of an electric motor, and while the theory may be elaborated upon, as in the following, it should be borne in mind that the fundamental principles are simple and easy to comprehend.

The development of a magnetic field within a loop of wire, when affected by a current of electricity by which it acquires all the qualifications of a magnet, was first discovered and enunciated by Oersted. Thus is became subsequently possible to express magnetism qualitatively and quantitively in terms of electricity. In other words, it was found that magnetism produced by electricity could be calculated with exactitude, and the polarity as well, anticipated. Each turn of wire carrying a certain current can be regarded as a lamellar magnet possessing a certain magneto-motive force. A succession of such small magnetic pumps, as they might be called, force the magnetism through the medium whether it be iron or air. As the number of them is augmented, and the current in them increased, their power or magneto-motive force increases in proportion. Thus, when such coils are so situated that their influence upon each other is productive of motion, it becomes evident that the power produced mechanically is in proportion to the magnetic pull resulting from the arrangement of coils and poles, and the rotative speed.

Relation of Lines of Force and Current

The lines of force, when meeting those of another field, tend to set themselves parallel, or as it would seem, tangent to those of the other field. When a bar of iron is inserted within a series of electro-

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magnetic helices its polarity becomes most pronounced and manifests itself, if movement is possible, by motion towards an opposite pole or away from a similar pole. When the magnetic field of a motor is considered, its lines of force pass between the two poles via the armature core of laminated iron placed within it. A coil of wire wound around this core can occupy a series of positions with respect to the horizontal or vertical plane. Let three positions be considered—one in the horizontal plane, one in the vertical plane, and one in a plane situated at an angle of 45 degrees, as shown in Fig. 14. This coil, we assume, has as yet exercised no influence upon the magnetic field which streams across from the north pole to the south pole of the motor. It is then to be considered as occupying the first of the positions referred to, namely, one in the horizontal plane, as shown at *A*.

On sending a current through the coil when in a position in the horizontal plane, it acts in every respect as any other electro-magnet irrespective of the fact that it is already in a magnetic field. The turns of wire which compose it act upon the armature core of laminated iron which they embrace, and magnetize it. If a coil were in a horizontal

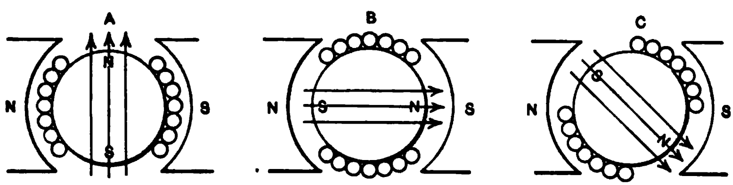

Fig. 14. Graphical Illustration of Action of an Electric Motor

position in space, and did not contain any iron, it would produce a comparatively weak field, but whose lines of force would lie in a vertical direction. Situated as it is with a core of wrought-iron between the poles of a powerful field, the same phenomenon takes place. The coil produces a vertical field, a field in fact whose lines of force are at right angles to those of the original field. It would tend to move the now vertically suspended electro-magnet so that its poles would seek the opposite poles of the surrounding field. The motion would be one of rotation either to the right or to the left, depending upon the relative position of the poles produced by the ampere-turns of the horizontal coil and those of the field in which the armature core rests. The lines of force of the coil will, if permitted, set themselves parallel to those of the field, and in so doing motion would be produced.

A coil situated in the vertical plane, as shown at *B* in Fig. 14, produces a magnetic field at right angles to itself or in a horizontal plane. Its lines of force would therefore merge with those of the surrounding field, or, if the poles were opposed to each other, reduce it to an extent dependent upon its magneto-motive force. In either case, whether the field is augmented or reduced, no motion will tend to result from such a relative position, as the lines of force are now in a position of parallelism with respect to each other.

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It is evident from the positions of the coil in a horizontal and vertical plane that these are not the ones best suited to the production of either great pull or torque or motion. A coil at an angle of 45 degrees, however, producing a magnetic field at right angles to itself as shown at *C*, Fig. 14, also presents poles in a position with reference to those of the field surrounding it, so that motion must result. Not only will a tendency to swing around be perceived, but a strong pull will accompany it. The lines of force of the coil can set themselves parallel to those of the field only by moving the core. This will actually take place not only when coils occupy a position at 45 degrees to either the horizontal or vertical plane but when they are slightly inclined to either. Thus it becomes evident that the constant effort taking place between the lines of force due to the coils on the armature and those of the field, which are supposed to remain comparatively unchanged, can only take place when they occupy certain positions with respect to the field. Under these conditions it might be said that the circumstances present the case of one fixed magnet whose field generally retains its position and a series of movable electro-magnets whose fields are constantly tending to assume positions in which their lines of force lie parallel to and in the same direction as those of the field. Increasing the current under these general conditions would mean an increase in pull between the stationary magnet of the field and the movable electro-magnet caused by the various positions of the coils on the armature. The torque of the armature, therefore, is entirely a question of magnetic field and current in the armature, which is merely another way of saying that it is simply a question of the amount of pull resulting from a stationary and a movable magnetic field, the latter being capable of increasing by an increase of current.

Magnetism and Mechanical Pull

The relation existing between magnetism and mechanical pull, in the case of an electro-magnet, to the poles of which a piece of iron or armature is to be attracted, is very simple. The formula for this relation gives the pull in dynes as follows:

$$P = \frac{B^2 \times A}{8\pi}$$

in which

P = pull in dynes,
B = lines of force per square centimeter,
A = area in square centimeters,
π = 3.1416.

To illustrate the application, take the case of a magnet having 100 square centimeters of pole surface, and the lines of force equal to 10,000 per square centimeter. The calculation will show the following result:

$$P = \frac{10{,}000 \times 10{,}000 \times 100}{8 \times 3.1416} = 398{,}000{,}000 \text{ dynes} = 895 \text{ pounds.}$$

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The Counter Electromotive Force of a Motor

The adjustment which takes place between the load of a motor and the power it consumes is brought about by means of the counter electromotive force. This electromotive force is developed within the armature for the same reason that any other electromotive force is generated in conductors cutting a magnetic field. The armature of the motor, although caused to rotate by the reaction between the field of the magnets and the field of the conductors, nevertheless presents the case of free conductors rotating in such a manner that the lines of force they meet are cut and necessarily produce electromotive force. It is a simple matter to calculate this counter electromotive force by multiplying the revolutions per second by the number of conductors by the lines of force of the field, and dividing by 100,000,000.

The conditions which exist within the armature of a motor when in action are as follows: Current is allowed to enter the motor, energizing the field magnets, and passing through the armature in a limited

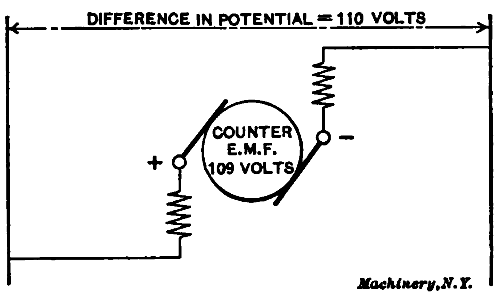

Fig. 15. Graphical Illustration of the Principle of the Counter Electromotive Force

manner. The rotation which then ensues is the means of generating an electromotive force within the armature conductors. There are, therefore, two electromotive forces in action within the armature, one of which tends to send a current through it, and the other, which opposes or counteracts the effect of the entering electromotive force. The electromotive force *generated* within the armature conductors is called the counter electro-motive force, and the electromotive force applied to the motor is called the line or impressed electromotive force.

A study of electromotive force with respect to its generation by means of motion, lines of force and conductors, shows how variations in the amount of electromotive force developed may be brought about. Any increase in the number of conductors on the armature of a motor will give rise to a higher counter electromotive force. Any change in the speed of a motor will give rise proportionately to an equivalent change in the counter electromotive force of a motor. Finally, any increase or decrease in the strength of the magnetic field will be the means of causing a change in the counter electromotive force. These influences are referred to because the regulation and operation of mo-

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tors is dependent upon these principles not only in theory but in actual practice.

When an impressed electromotive force acts upon the field and armature windings of a motor, current is sent through the first, producing a field of given strength, and through the second producing rotation and, hence, power. The remarkable fact about the work a motor is doing and its counter electromotive force is this: When the motor is running free, or "idle" as it is called, the motor is developing the highest counter electromotive force, and in consequence the impressed electromotive force is only able to send a small current through the armature. The effective electromotive force in this case is the *difference* between the impressed electromotive force and the counter electromotive force. This effective electromotive force will send a current through the armature which is governed by the resistance of the same. For instance, assume that the armature has a resistance of 0.01 of an ohm, that the impressed electromotive force equals 110 volts, and that the counter electromotive force equals 109.5 or 109.75 volts. The difference between 110 and 109.5 volts is 0.5 volt, which gives a current of $0.5 \div 0.01 = 50$ amperes. The difference between 110 and 109.75 volts is 0.25 volt and this would send a current through the armature of $0.25 \div 0.01 = 25$ amperes. Therefore a very low resistance armature needs but a very small effective pressure to send a heavy current through.

The frequent changes of load to which a motor is exposed will, when taking place, vary the speed slightly. If the load is reduced the speed will increase, and if the load is increased the speed will diminish. It is thus evident that the counter electromotive force will vary accordingly, and that less or more current will pass through the armature. The counter electromotive force, therefore, acts as a natural automatic valve which opens wider when the load on the motor is increased, and therefore more current is required, and which, so to speak, closes down when the load on the motor is diminished and less current is required.

Kinds of Motors

Motors are divided up into classes according to the winding and the character of the current employed for the operation. The direct current is used for motors wound as follows:

Constant current series-wound motors. (See *A*, Fig. 16.)
Constant potential shunt-wound motors. (See *B*, Fig. 16.)
Constant potential differentially-wound motors. (See *C*, Fig. 16.)

Each of these types is distinct, as far as its winding is concerned, although the last is a combination of the first two, that is, shunt and series winding. Series-wound motors are employed on direct current circuits which supply constant current and constant potential. High tension arc light constant current systems make use of them, as well as 550-volt constant potential street railway systems. The shunt-wound

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motor is used for stationary work, such as the running of machine shops, printing presses, etc.

Speed of Motors

The question of speed is a very important one in connection with motor design and construction. The two possibilities open in this direction are *constant* speed and *variable* speed. The speed can be controlled and varied by placing a resistance in series with the motor, thus controlling the volts and amperes it receives; but automatic control is, perhaps, more easily obtained, in such cases when a constant speed is desired, by differential winding. The ordinary type of shunt-wound motor possesses a fairly constant speed when the load is increased or diminished, whereas the series-wound motor will increase in speed as the load is reduced and decrease in speed as the load is increased. A differentially-wound motor is one constructed with a differential field, that is to say, a field whose magnetic strength is increased or diminished, not with the increase of the load, but reversely. In a motor of this type of winding its field is weakest when

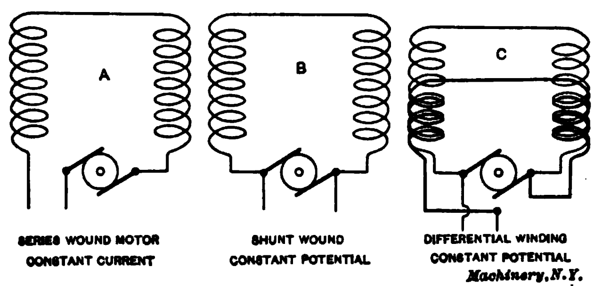


Fig. 16. Types of Motor Windings

its load is greatest and its field is strongest when its load is least. The manner in which this affects the speed will be explained shortly under the head "Differentially-wound Motor."

The Series-wound Motor in Service

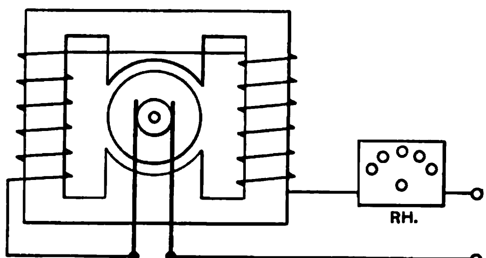
To understand the service for which a series-wound motor is best suited, it is necessary to understand the influence upon it of more or less voltage, more or less current, and a heavier or a lighter load. To begin with, the very nature of a series winding calls for the same current in both armature and field. This fact is emphasized in order to show how responsive the motor is to such changes as may occur in the counter electromotive force of its armature. The current which passes through a motor may be determined by the formula:

$$\text{Current} = \frac{\text{volts of line} - \text{counter E.M.F.}}{\text{resistance in ohms}}$$

Supposing a series motor has a resistance through armature and field of 2 ohms, and its armature develops a counter electromotive force of 400 volts; then, if the impressed or line pressure is 500 volts, the current will be:

$$\text{Amperes} = \frac{500 - 400}{2} = 50.$$

Examination of this formula will show that if the resistance is increased the current will diminish, and also that an increase in the counter electromotive force will reduce the current. It will show in addition that if the voltage supplied to the motor is increased, more current will flow; there will therefore be more torque or pull to the armature and in consequence a higher speed. Manipulation of the field strength is the means employed for affecting the counter electromotive force; in this case, if the field is cut down either by shunting the field winding or by short-circuiting part of the lines of force, less lines of force are cut by the armature conductors and a lower counter electromotive force is produced. More current cannot pass in if the machine is series wound and fully loaded on a constant current cir-



Machinery, N.Y.

Fig. 17. Series Motor with Resistance

cuit. Therefore, under such conditions, with a weakened field its pull would be reduced and its speed slackened. As already stated, a series motor increases in speed as its load is reduced and diminishes in speed as the load is increased. A reduction of the load causes the then present pull of the motor to increase its speed; this also increases its counter electromotive force and consequently reduces the current in both armature and field. Although there is now a weaker field due to fewer ampere-turns on the field magnets, there is a higher speed. A still further reduction of the load will increase the speed still further until, if the motor is entirely without load, it will run fast enough to destroy itself.

In street railway service the series motor is used exclusively, and its regulation in regard to speed and power is carried on by a controller which throws the motor circuits from being in series with each other, eventually into multiple, it being understood that more than one motor per car is in operation at a time. A series motor with a resistance box in series with it, as shown in Fig. 17, represents in many respects the method of controlling a street car motor, only, instead of a resistance of this character, its place is taken by another series motor, as shown

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in Fig. 18; two series motors in series, and if necessary, with a resistance in series as well, being the present basis for street car control. Either a resistance, or another motor in series, is a means of reducing the pressure and current supplied, which is theoretically and, fortunately, practically a successful method of governing the speed.

The motorman is merely manipulating the circuits of the series motors, so that more or less current and pressure is allowed to affect each motor individually, for the purpose of giving the car a greater or less speed. It has been stated that a series motor running idle, that is, without a load, will tear itself to pieces. In street car service, even though the car is empty, the motor has still the work of carrying the car trucks and car body, and, therefore, cannot develop an abnormally high speed. But it will be readily noticed how much faster an empty car travels, than one filled with passengers. The motors in this case are taking all they possibly can in the way of current at the pressure of the line. Higher voltage would mean an increased speed, or a more powerful field, but the limited pressure of the trolley system, 550 volts, forbids this, and the only means for moving more heavily loaded cars is more powerful motors.

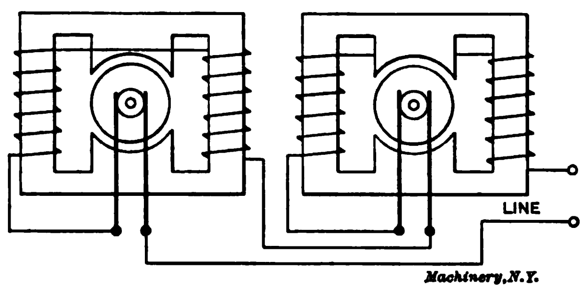

Fig. 18. Two Series Motors in Series

Fan motors are series wound as a rule, unless they are to serve a different purpose from that of only running fans. A series-wound motor must always be doing work when in operation, and the presence of a fan, therefore, represents a load which enables it to comply with the requirements of practice. Different speeds are obtained by means of a switch which governs resistance in series with the motor. At two or three points the switch allows a current of great strength and pressure to enter, which, with the fan load permanent, permits of a higher speed. A series-wound motor for the driving of sewing machines could not be used unless there was a certainty of the load never being removed; otherwise the armature of the motor would fly apart. Intermittent service calls for a motor which can meet conditions of full load or no load without such an abnormal development of speed.

The Shunt-wound Motor

The shunt-wound motor is one in which the speed is fairly well preserved under all changes of load. The field winding receives its cur-

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rent in multiple from the line, and therefore is not affected by the changes in speed or load. The counter electromotive force of the armature is the regulator of the amount of current the motor takes, and this in its place is determined by the amount of work the motor is doing and its effect upon the speed. As the load is increased or diminished on a shunt-wound motor, the speed is affected accordingly; but the counter electromotive force will rise or fall, which will be the means of allowing a current to flow through the armature proportional to the effective electromotive force. The automatic action of the counter electromotive force in this respect has made the shunt motor peculiarly noteworthy. Under these circumstances, it is easy to increase the speed of the motor by means of the field.

If the field of a shunt motor is weakened, the counter electromotive force of the armature would either drop, or (on account of the increased current which would thereby result, and necessarily the greater torque in the armature), the speed would increase. This is found to be the case in practice. That is to say, if a resistance is put in series with the field winding of a shunt motor, the speed of the motor will either increase or decrease as the current in the field winding is decreased or increased. A very interesting experiment, which carries out this idea in practice, is that of running a shunt motor idle and suddenly cutting out the field winding. The effect of this, which should be tried with a small motor, is to raise the speed to a very high point. The motor is not entirely without a field in this case, but depends upon the residual magnetism and armature reaction for that which exists. The counter electromotive force thus suddenly cut down, causes a powerful current to flow through the armature. The effect of this is a greatly increased torque and a higher speed, until, if the motor can stand the strain, it reaches a speed at which there is some approximation between the counter and impressed electromotive force to that existing under normal conditions. Advantage of this fact is taken in the regulation of shunt motors by the so called differential method. By this method the field is weakened when the speed slackens.

Differentially-wound Motor

The differential field is obtained by means of two field windings—one a shunt winding and the other a series winding, as shown in Fig. 19. The shunt winding receives its current and pressure as usual from the main line, but the series winding takes the entire current of the motor. This winding is so arranged, that as the current required by the motor increases, its *demagnetizing* effect upon the field also increases. It is really a compound-wound dynamo turned into a motor. Thus, increasing load means a tendency to increasing speed, which compensates for the number of turns per minute lost through the increased load. When the motor runs idle, the current in these series turns has little or no effect on the speed. In fact, the motor is now a simple shunt-wound machine. A uniform speed is secured by this means, within certain limits, for all changes of load.

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Conditions of Service

The two broad groups in which motors may be divided, as far as service is concerned, are the class including motors for stationary, and the class including motors for vehicle purposes. Stationary service may be still further divided as below:

Factory drive, all kinds.
Ventilation, including fan motors.
Hoisting and elevator service.
Mining, such as drilling, etc.

The conditions of service for stationary motors may be extended so as to include applications of less importance, such as dental apparatus, medical appliances, stage devices, etc. The other list of conditions of service, in which the motor is employed for transportation from point to point is as follows:

Electric railway work.
Automobile work.
Launch work.
Agricultural work.
Mining work.

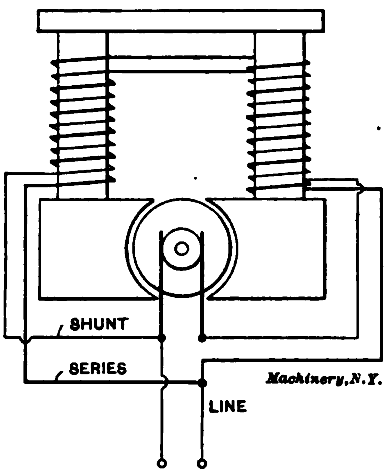

Fig. 19. Differentially-wound Motor

Depending upon the nature of the application of the motor to any specific purpose, the character of the motor itself is determined. This is the influence which gives rise to the employment of series, shunt or differentially wound machines, taking a direct current, or the installation of motors taking an alternating current.

Starting a Motor

To start a motor from a condition of rest requires the employment of a device which will not permit more than the proper quota of current to pass through. In a series motor a resistance interposed between the line and the motor will prove sufficient. In a shunt motor it is necessary to take certain precautions in this direction, so as to limit the flow of current through the armature. Enough time must elapse from the moment the current is turned on until the resistance is cut out, to permit the armature to develop sufficient back electromotive force to act as a restraining influence upon the current. The correct function, therefore, of the resistance is to act as a substitute for the counter electromotive force. It must be remembered that the field windings of a shunt motor are connected across the line and take their energy directly from the circuit. The armature will be connected in the same way *after* the motor is running; but until the

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motor is developing enough counter electromotive force, a resistance is kept in series with the armature, as shown in Fig. 20. First when the speed is high, is it deemed safe to gradually cut it out. It is thus evident that both field and armature are in multiple with the line receiving the full pressure, but the armature is protected from excessive current when starting, by a resistance in series.

As an example, suppose that the armature itself has a resistance of 0.02 ohm. If no starting resistance were employed, and a 110 volt current were sent through the armature, the strength of the current would be $110 \div 0.02 = 5500$ amperes, which would be destructive to the windings of the machine, causing short circuit. A starting resistance or rheostat, frequently also called starting box, is therefore employed to prevent the strength of the current to rise beyond a reasonable value.

If a resistance box of from 10 to 20 ohms is selected, to put in circuit with the armature, then, even though the armature does not revolve very fast, only 5 or 10 amperes can get through in the beginning, and the danger of a short circuit is removed. After the armature speeds

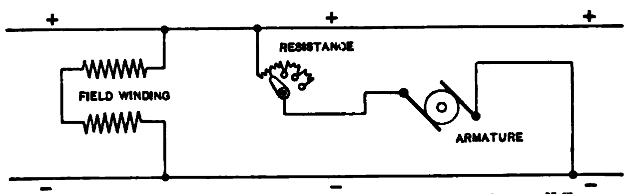

Fig. 20. Resistance in Series with Armature when Starting Motor

up, however, the resistance is cut out, the counter electromotive force bringing about the proper adjustment between the load and the current consumption. If in the case under consideration, the counter electromotive force is equal to 109 volts, then a voltage of 1 volt, with an armature resistance of 0.02 ohms, will send a current of 50 amperes through the armature winding at full load.

It is evident that the resistance used must bear a definite relation to the capacity or horsepower of the motor. Hence, rheostats are termed, for example, 110—2 H. P. resistance boxes, or whatever the voltage and horsepower may be in each case.

It should be understood that the current a motor takes is largely a question of its efficiency. For instance, a 10 horsepower motor will take a theoretical current of 74.6 amperes at 100 volts pressure. The total watts are $10 \times 746 = 7460$; but if the efficiency of the motor is not high, it will take more watts in proportion, which with given pressure would mean more current. The amount of current required by a series of motors of 10 horsepower apiece at varying efficiencies could easily be tabulated. Such a table would be exceedingly instructive in showing the relationship between efficiency and the consumption of power. It is not difficult to estimate that a motor of low efficiency will waste in a certain period of time, an amount of power, the cost

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of which will compare readily with its own cost. In other words, if a motor is cheap because its construction makes it inefficient, it is for that very reason dear, because its power consumption makes it expensive. A high efficiency motor is therefore cheapest, though its first cost may be greater. Another point of great interest is that of speed. Small power users are peculiarly addicted to the habit of overloading motors. Jacobi many years ago enunciated the principle that a motor is doing its maximum work when its speed is one-half its normal speed, through being loaded down. At this rate of speed and load, it has only 50 per cent efficiency. It is therefore consuming twice as

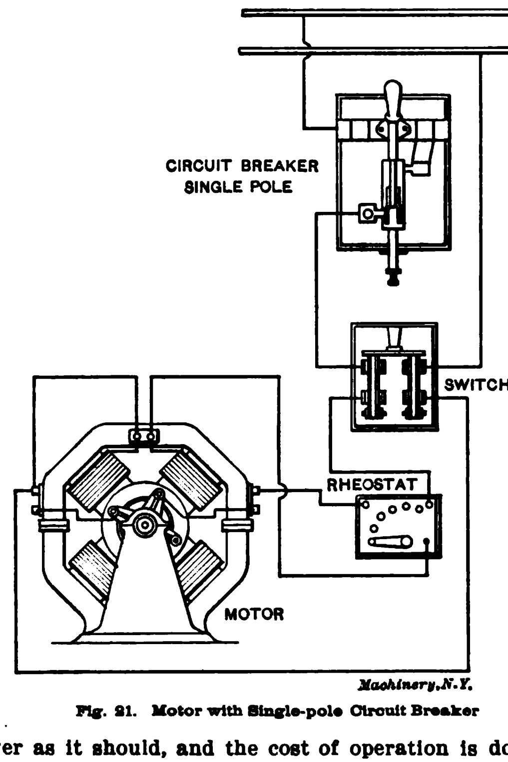

Fig. 21. Motor with Single-pole Circuit Breaker

much power as it should, and the cost of operation is doubled. While it is true that a motor can do more work if overloaded, it does that extra work on a very wasteful basis. It is not wise, therefore, to place a strain beyond the normal rating upon any motor, unless it be for the purpose of bridging over an emergency for a short period of time.

Circuit Breakers in Motor Service

The possibility of sudden overload with the resulting inrush of current has been the reason for introducing the circuit breaker, or electro-magnetic switch, for the protection of motor as well as dynamo lines. The electro-magnet and switch, of which it is composed, are

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simple enough in general construction, but the electro-magnet must be sensitive to a certain value of current, so that if this point is passed, the switch will fly open and disconnect the motor from the line. The switch is so constructed that when it flies open, its action is sudden and arc-less. The circuit breaker is a substitute for the old time fuse, whose dangerous volatilization was an ever present risk of fire during a temporary short-circuit. Motor and dynamo circuits protected with circuit breakers are like boilers supplied with safety valves weighted down with a certain number of pounds. In one case steam pressure will set the valve into sudden operation, in the other case an overflow of current.

A line connecting to either a motor or generator may be protected by the installation of a single pole (see Fig. 21) or a double pole (see

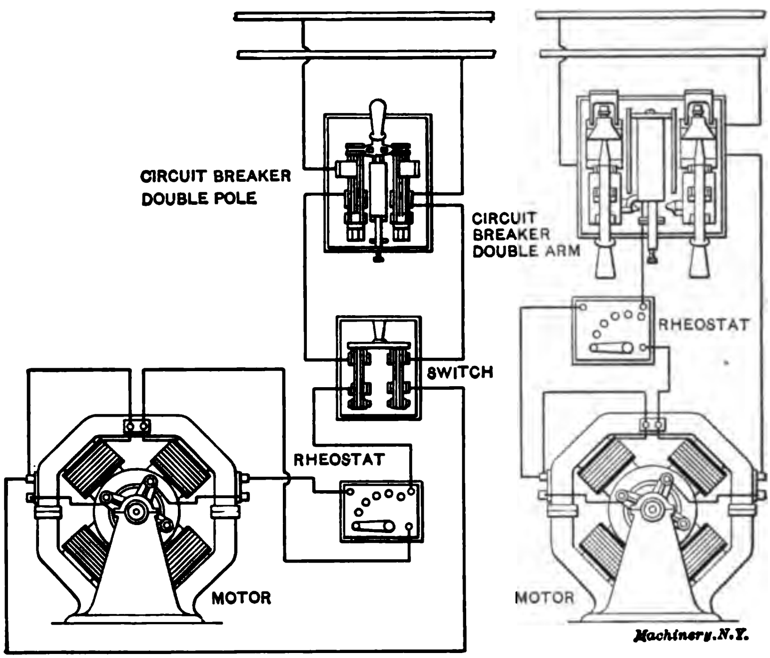

Fig. 22. Motors with Double-pole Circuit Breakers

Fig. 22) circuit breaker; by this is meant a circuit breaker which is inserted in only one leg of the line involving a single pole, or one engaging both wires or poles.

Commercial Efficiency

The rating of motors for commercial efficiency is based upon the tests to which they are subjected. The tests are simple in character and may be defined as a method of establishing the ratio between the power taken out in a mechanical form to the power sent in, in an electrical form:

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$$\text{Commercial efficiency} = \frac{\text{mechanical energy obtained}}{\text{electrical energy supplied}}.$$

The motor is supplied with an ammeter and voltmeter to measure the electrical energy sent in, as indicated in Fig. 23. A tachometer or speed meter is utilized for getting the number of revolutions of the armature per minute. A dynamometer or brake is used for measuring the pull on the pulley or shaft of the motor. If the pull on the dynamometer or brake is taken at a certain rate of speed, it will be accompanied by a certain current consumption, the voltage remaining the same. This data is used for determining the efficiency as follows:

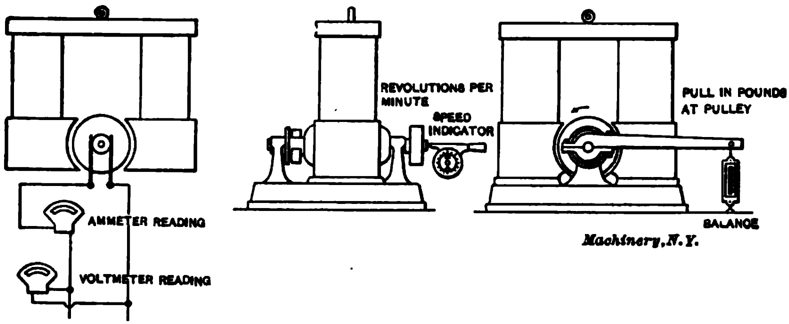

Fig. 23. Method of Testing Motors

$$\text{Mechanical H.P.} = \frac{\text{Pull in pounds} \times \text{length of brake arm in feet} \times \text{rev. per min.} \times 2 \times 3.1416}{33{,}000}$$

$$\text{Electrical H.P.} = \frac{\text{Amperes} \times \text{volts}}{746}$$

$$\text{Efficiency} = \frac{\text{Mechanical H.P.}}{\text{Electrical H.P.}}$$

The efficiency is obtained in this manner for all such loads as running idle, quarter load, half load, three-quarter load and full load. The speed, amperes, and pull, will vary in each case, the amperes and pull naturally very much more than the speed.

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CHAPTER III

ELECTRIC RAILWAYS

The inventors of electric railway appliances may be counted in multitudes, and their work in the aggregate has been the means of developing the possibilities of electric roads to their present high state. It must not be believed, however, that perfection has been reached as yet; far from it. Yet judging from present conditions, the most definite lines of the problem have been laid down, and further work will be mainly in the line of secondary improvements. The first recorded American inventor in this field was Davenport, who built a small model of an electric car running on tracks, very crude, yet operative, and thoroughly crystallizing the fundamental principles of electric railroading. Among the first applications of the electric motor naturally would be that of applying it to some purposes of traction. Jacobi applied an electric motor run by batteries to the running of a small boat on the river Neva, and the same idea was followed by Trouve in France on the Seine. It was found possible to operate tricycles and small four-wheeled vehicles by electricity, and then a small electric car. The experiments carried on in the initial stages of electric traction were destined to expand, because of the rapid increase of population in large cities, which called for some efficient and safe as well as rapid means of locomotion. The laboratory experiments and scientific tests soon became matters of public interest, and the question of whether the application of an electric motor to a railway truck would prove a success was soon answered in the affirmative.

Systems of Electric Roads

A number of systems of electric roads have been designed whose ultimate object was the solution of the street car problem. Some of them have been tried with every sign of success at the start and have failed, others have been failures in the beginning, but are now established successes. The four principal systems to which general reference is made are:

1.—The overhead trolley system.
2.—The third-rail system.
3.—The open conduit or slot system.
4.—The storage battery car system.

The overhead trolley system is of American origin. It consists of one, or sometimes two wires, suspended over the track and carrying the current. The overhead wire is placed at a sufficient height so that it will not affect street traffic in any way. Poles for supporting the wire are placed either along each side of the street, or in the center of the street between the two tracks in double-track systems. When

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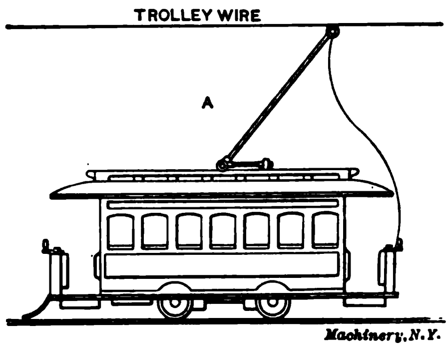
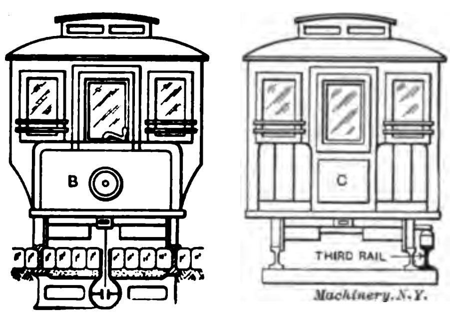
only one overhead wire is used the return is through the rails. When two wires are used the return is through one of the wires. The overhead trolley system is the cheapest to install and maintain, and with proper care in erection and maintenance it is safe and durable. The main advantage of this system is, of course, the small first cost, and the comparative ease with which it can be kept in repair. The chief objection to the overhead trolley system has been on grounds of its appearance. But this objection can be largely overcome by making



The Overhead Trolley System



The Conduit System The Third-rail System

Fig. 24. Principal Electric Railway Systems

the poles supporting the wire of ornamental appearance, and using them for arc and incandescent lighting purposes as well.

The third rail system differs from the overhead trolley system in that the current is transmitted through a rail laid on one side of, or between, the tracks. In the open conduit or slot system, a continuous bare conductor is placed underground in an open slotted conduit between the rails, the current being taken off from the conductor by some sliding or rolling contact carried on the cars. The storage battery car system, as the name indicates, depends for its motive power on storage batteries charged with current from a central station. In this case it is evident that the car becomes independent of line conductors.

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It is not difficult for the reader to realize that a selection of the correct system, from among those mentioned, suited to the special needs of cities and to suburban use, was a matter calling for the greatest discrimination. It has been pretty well settled in New York that the open conduit is best suited to the peculiar requirements of a large city, where it is imperative to place all wire underground, thus excluding the overhead trolley entirely. The storage battery system was in operation for a few years under the title of the Julian system, but it did not succeed on account of the wear and tear of batteries, the difficulty of handling the same, and the possibility of breakdowns in the midst of busy thoroughfares. The weight of the storage battery added to the problem, with the result that a continuation of the experiment led to great financial sacrifices. Of late, however, the experiments have been successfully resumed with the Edison storage battery.

The open conduit system was a failure for many years because of the imagined difficulty of keeping the conduit clean, and because of the impracticability of many new devices introduced to make it a success. Insulation, drainage and a system of manholes for inspection were the elementary considerations. Along with them came the correct development of a solid and effective method of construction. Sewage connections were made adequate to drain the conduit, and a substantial form of insulator was introduced to support the two rails acting as conductors within the conduit. Ducts with feeders were laid along the tracks, and thus the various, and at one time, apparently insurmountable obstacles, were overcome. The peculiarities of street car service are such that a car must start rapidly, yet without too sudden acceleration. To accomplish this successfully, powerful motors with properly designed controllers, are installed in the cars.

Having now reviewed in a general way the conditions of electric railway systems we will examine the most important systems in detail.

The Overhead Trolley

The cars in the overhead trolley system are fed with current from the trolley wire and tracks. The trolley or pole ends in a trolley wheel which presses against the trolley wire and completes the circuit. The trolley wire, of No. 0 size Brown & Sharpe gage, is supported above the track by means of wires and poles which hold it over the middle of the track. The rails are electrically connected by copper bonds which join adjacent ends. Both trolley wire and tracks are reinforced at intervals by means of additional supply wires called feeders. The current enters at the trolley wheel, passes down the trolley and enters the motors via the controller. The name controller is obviously the best that could be chosen, because by means of this device the current supply is controlled and the speed and power of the motors properly regulated. The pressure employed for trolley car service is generally 550 volts. This is not supposed to be of sufficient strength to destroy human life, although many instances have been recorded of such unfortunate circumstances.

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The trolley wire is made of hard drawn copper and the wires stretched across the track from pole to pole are called *span* wires. The trolley wire is also supported from brackets attached to or forming part of the posts, which are partly or wholly of metal. The construction in this respect must be such that the trolley wire, though firmly held, is still elastic. At various points along the trolley line, where the traffic is heaviest, the wire is connected to feeders. It is also connected to feeders at those portions of the system furthest removed from the power house. These more or less distant points do not suffer so much from heavy traffic as from the effects of heavy drop. As each car takes from 50 to 150 amperes, depending upon its load and speed, and as the resistance of a few miles of wire, however large in size, is quite an item, it becomes evident that the degree of drop in voltage will be quite a percentage of the total pressure. This would cause the cars to run slow for two reasons—first, because the voltage is low, and second, because the current is less because the voltage is low. The series motor is controlled, as regards its pull and speed, by just such conditions as those described, which can be incorporated into the general statement that where series motors are concerned, as already mentioned in the previous chapter, the following rules apply:

1. In a series motor the pull increases if the current increases and the pull decreases if the current decreases.

2. In a series motor the speed increases if the voltage at its armature terminals increases, and its speed decreases if the voltage at its armature terminals decreases.

Suppose six miles of wire are considered of an average resistance of ½ ohm to the mile; this would give a total resistance of 3 ohms. If one or two cars are consuming about 150 amperes at this point, the drop in the line equals $3 \times 150 = 450$ volts. It is easy to realize how completely a trolley system would fail under these conditions. In fact, a dozen cars would be the means of causing so complete a drop that practically no available energy would reach this distant point. It is no exaggeration to state that in a large city a trolley system is an impossibility unless hundreds of tons of copper, in the form of feeders, are employed to carry current all along its circuit. The trolley wire, therefore, is not actually carrying the whole electrical energy, but the feeders. The problem is one of reducing the drop to a certain practical minimum, which involves one of the heaviest investments in electric railway engineering.

Bonding

All that is required in ordinary railroad practice is to firmly secure the rails together mechanically by means of fish plates. This method of joining steam-road rails is mechanically good, but for electric railway service it is unsatisfactory. Rust soon prevents a good contact, and the result is a high resistance joint. A series of such defects would rapidly use up the voltage when a heavy current is required; hence, an electrical contact is secured by means of *bonding*. To bond

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the rails means to establish connection between them by means of a heavy flexible copper wire or cable. The ends of this wire or stranded cable are riveted into the rail, the rivet and joint being proportioned with respect to the current which passes. The rails when bonded represent two long lines of electrical conductors upon which the wheels turn and also complete the circuit through the motors from the overhead trolley wire.

Another method of bonding is to run a wire or cable along the middle of the track and attach wires to it from the rails. In other instances the wire laid between the tracks zigzags from rail length to rail length and establishes connection. The most ideal method, however, is to weld the rails into one continuous track. Track or rail welding is

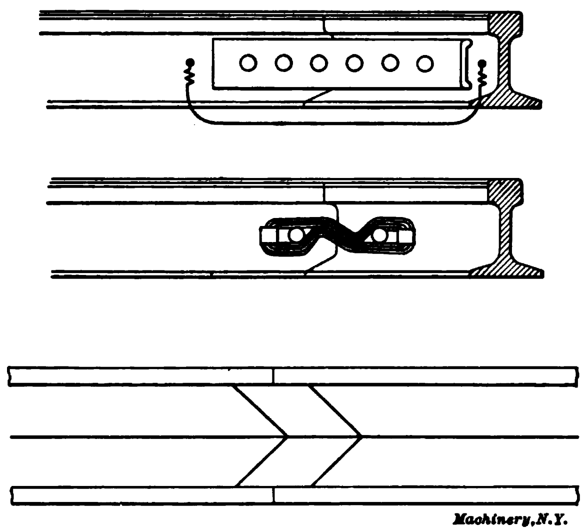

Fig. 25. Methods of Bonding

the most satisfactory in the end for all the reasons which appeal to the electrical expert. The other methods though good are subject to conditions which eventually destroy their integrity. If the resistance at any one bonding averages up 1/100 of an ohm, then 1000 bonds give a resistance of 10 ohms. As this is duplicated on the other track as well, and as this track is in multiple, the net resistance would be 5 ohms. Reducing the average resistance of any one bond will still give for the aggregate resistance a very high figure. The most important difficulty lies in the fact that bonding steadily depreciates in quality. Iron and copper form a voltaic couple, which helps to increase the bad effects of general corrosion due to ordinary causes. A current of 1000 amperes given up by the line at any particular spot, due to a block of cars and the almost simultaneous starting of a group of them, would cause a very heavy line drop unless the resistance is exceed-

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ingly low. It is readily seen that a resistance of 1/10 of an ohm means a drop of $1/10 \times 1000 = 100$ volts. On a 550 volt circuit this means a loss of nearly 20 per cent of the total voltage. Examples of different methods of bonding are shown in Fig. 25.

Electrolysis and Bad Bonding

The energy which is not conducted through the tracks will pass through all the available gas and water pipes in the neighborhood. The statement found in Ohm's law, that the current is directly proportional to the electromotive force and inversely proportional to the resistance, explains why the current will leak away from the tracks whenever the bonding is bad and take into its circuit water and gas mains. In passing from one to the other of these, the moist earth acts as the electrolyte and the pipes as the electrodes of an electrolytic cell. The metal is carried from point to point from the outer walls of the pipes as shown by the deep pitting which results. Thus the effects of poor bonding are manifested in two ways, through loss of power and through electrolysis.

In very wet weather these results are exaggerated, and the general leakage throughout the systems rises to very high figures. The two most readily controlled difficulties, however, are those found in a poorly fed trolley wire and a badly bonded track.

Double Overhead Trolley Systems

The double wire trolley system has been adopted only in a comparatively few cases in order to avoid all electrical disturbances in the returns. The system consists of two overhead wires, one positive and one negative, and two trolley wheels and poles. The current arrives at the motors *via* one wire and trolley, and returns to the power house *via* the other trolley and wire. The installation is more expensive than that of the single overhead conductor system, and difficulties are met with at junctions and crossings.

The Switch and the Controller

The current from the line after having passed through the trolley wheel and pole first passes a switch placed over the motorman's platform in ordinary street cars. At the other end of the car there is another switch, both switches being in series with each other. The current after having passed through the switches is led to a mechanical circuit breaker, so that the current can be automatically cut off in case of extreme overload, without causing injury to the motors.

The speed of rotation of the motors driving the car, and hence the speed of the car itself, is regulated through a controller operated by the motorman. By means of this controller and its rheostat the current can be so regulated and distributed to the motors that their power and speed can be regulated at will by the motorman. It may be explained that a rheostat is an adjustable resistance which enables the current to be brought to a standard or fixed value by adjusting the resistance. The term is generally applied to a quickly variable resistance, the varying values of which are known.

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The controller has been simplified in the last ten years until it has reached a point which approximates perfection. The car motors are designed with reference to the speed of the car, its weight and acceleration; the controller is designed with reference to the starting and stopping of the car, the current consumption, and the control of the circuits. If two series motors are considered, it is readily realized that the sudden throwing on of the power would result in probable accidents to those on board the car. The suddenness with which the car will start is largely dependent upon the current passing through the motors. If they are at rest, and the current is fully turned on, aside from the action of automatic circuit breakers, it is evident that with no counter electromotive force, an enormous current would tend to flow.

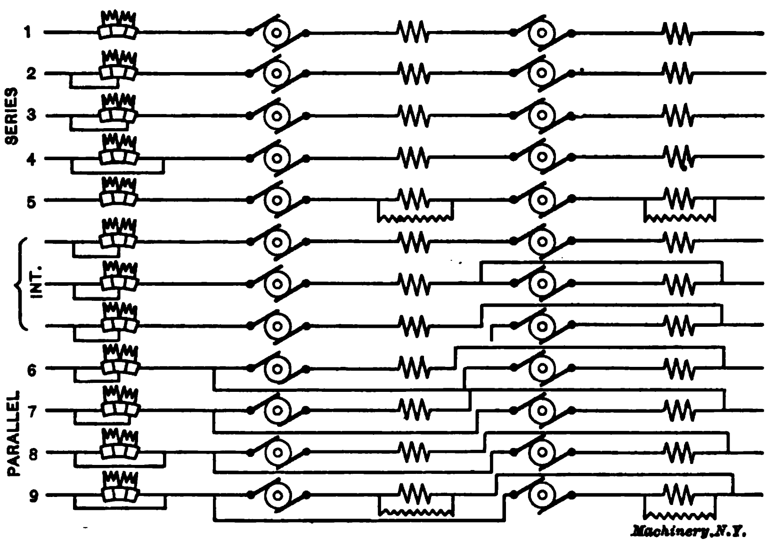

Fig. 26. Diagram showing Combinations Effected by Controller in Starting a Car

This would start the car with a jerk. The current governs the pull of the motor, therefore to avoid too rapid a development of torque the current must be introduced to the motors through the medium of resistance. A variety of connections must be made and unmade, so as to gradually bring the motors from a condition of rest to one of rapid motion. In the first step considerable resistance is interposed, and in the last both motors are in multiple across the circuit. Between these two extremes exists a series of steps or combinations as follows:

MOTORS IN SERIES

1.—Motors in series with a resistance and with each other.
2.—Motors in series with less resistance and with each other.
3.—Motors in series with still less resistance and with each other.
4.—Motors in series with each other (no resistance in).
5.—Motors in series with each other and fields shunted.

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MOTORS IN PARALLEL

6.—Motors in parallel with each other and resistance in.

7.—Motors in parallel with each other and less resistance in.

8.—Motors in parallel with each other and still less resistance in.

9.—Motors in parallel with each other and no resistance in and fields shunted.

These combinations are the ones effected by the General Electric K2 street car controller. As can be seen from the description given in conjunction with the combinations, it is of the series parallel type. There are really a series of combinations produced between 5 and 6 which are called intermediate connections. These are the connections which throw the motors from series into parallel. The equivalent of these combinations are given in diagrammatic form in Figs. 26 and 28, and represent the foundation on which is built the controller largely employed in New York, for street car, elevated and subway service. The combinations 1, 2, 3, 6 and 7 call for the use of the rheostat,

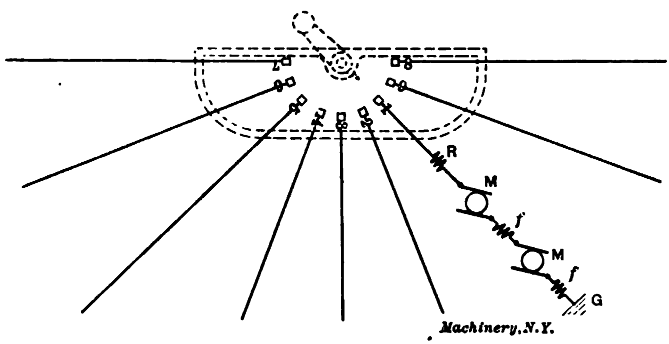

Fig. 27. Contacts of Street Car Controller

while combinations 4, 5, 8 and 9 do not; therefore, the former must never be used for any great length of time to run the car, while the latter are allowable. It is obviously wasteful to run a car with resistance in series, and this rule applies also to the intermediate positions lying between 5 and 6, which are cases where the rheostat is in circuit. Fig. 27 shows the controller contacts. In Fig. 28 the arrangement of the reversing switch is also shown, the movement of which to the right or left reverses the direction of rotation of the motors.

To sum up, the requirements for electric railway service, in general, are:

1.—The voltage along the system both in the tracks and trolley wire is sustained by means of feeders.

2.—The current, in starting, is introduced into the motor by an ever-increasing value by means of the controller.

With a uniform voltage along the line the speed will not drop, and with a uniform type of motor and with a scientifically constructed controller the ultimate motor torque will always be at a high figure.

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Long Distance Electric Roads

The adaptability of the overhead trolley system to long distance roads is evident from even a superficial examination of practical conditions. The greater the distance between the power house and the end of the road, the greater the cost of the system. This is true particularly with the old established method of using a direct current of 550 volts and an elaborate feeding system to reinforce the voltage and current. The capital invested per mile of track, including the cost of

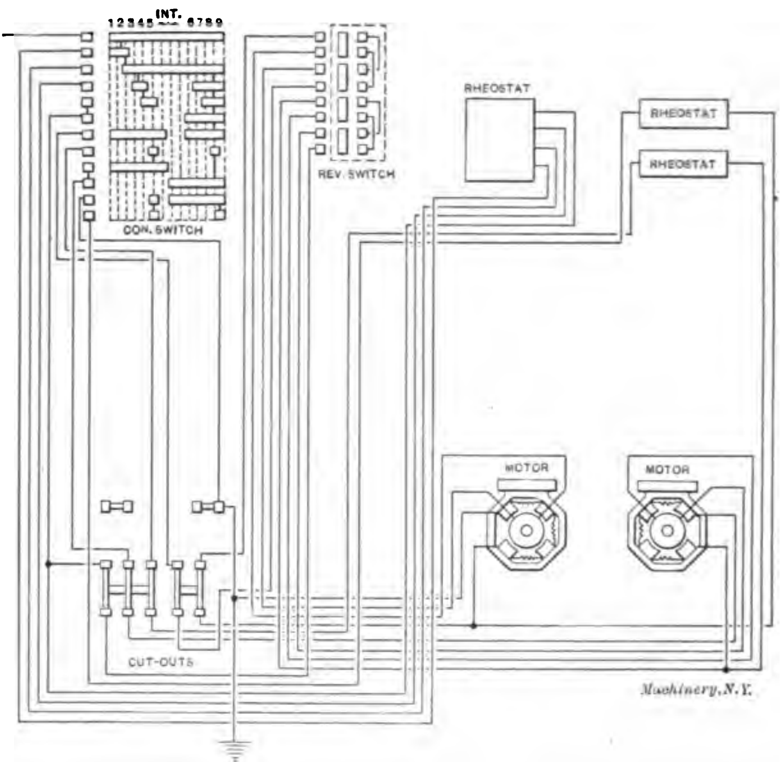

Fig. 28. Wiring Diagram of Street Car Motors and Controller

the power house, is the factor which in many respects limits the length of a line. Electric roads can be built to reach as far out into and across the country as steam roads, but the expense attached is high. Thus it becomes evident that engineering projects can only become established as definite propositions if their cheapness as well as practicability can be demonstrated. Long-distance roads must present the feature of high speed. In this respect the adaptability of the motor is unquestioned.

Within city limits the system in vogue is based upon the idea of substations. The power originally generated is converted into a high

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voltage alternating current which is distributed to a series of substations or transforming houses. From these, feeding lines radiate to different points of the electric road, sustaining the voltage, and leading, if necessary, to the end of the road. The longer the line, the more numerous become these subsidiary stations. This method of sub-stations is the one which has exerted an extraordinary influence upon the development of electric roads for street railway purposes within large cities. It has paved the way for a normal development of the electric street railway system; the flexibility of the alternating three-phase system aided by the application of rotary converters has placed electric railroading upon a broad and efficient basis.

The requirements of a long-distance road can be tabulated as a series of conditions imposed by the financial and scientific aspects of the problem; they are:

1.—High voltage for transmission.
2.—High insulation for the trolley line.
3.—Low cost per mile of road.
4.—Simple devices to control the car.
5.—Construction of a most durable character.

Though but part of the long list that a close inspection of the proposition would indicate, these items are the most important. To meet the first requirement in a practical and economical manner, experiments have been directed along the lines laid down by alternating current practice. It can be stated almost as a certainty that any great advancement made in electric railroad work will be by means of the direct application of the single-phase alternating current.

Third-rail and Overhead Trolley Compared

Comparison is frequently a better means of presenting ideas than mere description. The only difference between a third-rail and an overhead trolley system might be best expressed by the statement that one is an overhead trolley and the other is a ground trolley. In fact, no actual difference exists except in this respect, either in the character of the machinery employed or the transmission and distribution of the power. The advantage of solidly supporting a live conductor, namely, the third-rail, where it cannot fall, is counterbalanced by the difficulty of insulating it and its direct danger to the public. The third-rail is best suited to elevated structures, to stretches of protected track, to tunnels, etc. Tabulating the statements made, the case is presented as follows:

I. ADVANTAGES OF THE THIRD-RAIL	II. DISADVANTAGES OF THE THIRD-RAIL
Solidity of construction.	Difficulty of getting good insulation.
Cheapness of construction.	Danger to life.
Better conductivity.	Exposed to snow and rain.
Greater durability.	Requires frequent bonding.
Accessibility.	

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III. APPLICATIONS OF THE THIRD-RAIL

Elevated structures.
Protected stretches of track.
Tunnels.

In contradistinction to these factors are the advantages of the overhead trolley system, with the elimination of the necessity for bonding and the important question of the safety of the overhead trolley as far as life and limb are concerned. The question of insulation is obviously an open one, with greater advantages on the side of the overhead conductor. Climatic conditions, such as the effect of long continued rains, snows, and sleet storms, are obviously bad in both cases. At best, the overhead system is comparatively delicate, and unquestionably doubtful where long stretches of road are to be equipped. Constant inspection would be one of the only remedies for this, backed up, of course, by the use of the strongest and most reliable construction and material.

The Sprague Multiple Unit System

Whether trolley or third-rail is employed, the system of coupling and uncoupling carried out in a steam road, must be duplicated in any electric system which hopes to successfully compete in the open field. The Sprague multiple unit system presents an important feature—the possibility of connecting an electric car to another, or a third or fourth, and having but one motorman exercising control over the entire train. This remarkable feature of electric control, the ability to couple up electric cars, each equipped with their own motor, and all under the management and subject to the will of one man, has greatly furthered the development of electric train service. Both the elevated and underground systems employed in New York, are of the multiple unit system.

Electrical Systems for Regular Railway Service

Three important electrical systems are in use for regular railway operation. These systems are:

1.—The continuous- or direct-current, usually spoken of as the "third-rail" system, which employs alternating current for transmitting power when the distance is considerable.

2.—The three-phase alternating current system with two overhead trolley wires.

3.—The single-phase alternating current high-tension system with a single overhead wire.

A notable case of the latter system is the installation on the New York, New Haven and Hartford Railroad, where the motors and controlling apparatus are arranged to utilize single-phase current from an overhead trolley wire at 11,000 volts, and also to be operated by current from the 650-volt third-rail system of the New York Central and Hudson River Railroad. This installation demonstrates the wonderful flexibility of alternating current apparatus. The locomotive used on the New Haven road is provided with four motors each of 250

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horsepower nominal capacity. The motors are of the gearless type, that is, the armature of the motors is placed directly on the driving shafts.

The reasons given for the use of the single-phase alternating current system and its advantages for heavy traction service are stated as follows: Alternating current is used on account of its facilities for transformation. One trolley only is required, and with alternating current and one trolley wire, any desirable voltage can be used on the line. The type of motor employed can have its speed varied by varying the voltage supplied to it, and uses power practically in proportion to the load. The motor is of the variable speed type, and automatically adjusts its speed to that of the other motors driving the same load.

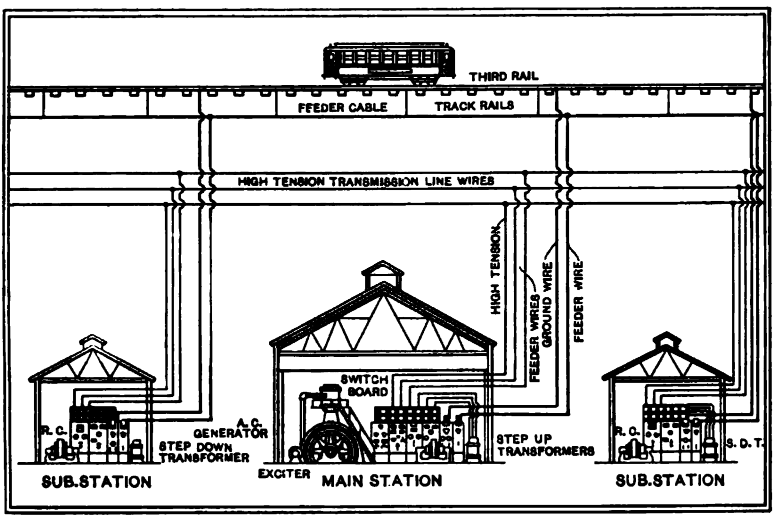

Fig. 29. Elements of an Electric Railway Undertaking

The locomotives of the New York Central and Hudson River Railroads also have their four driving motors applied directly to the wheel axles so that no gearing is required. The motors are 550 horsepower apiece, giving an output of 2200 horsepower, available at the wheels. A speed of 70 miles an hour is readily acquired by these locomotives, and a speed of 90 miles an hour may be obtained under favorable condition. The total weight of this locomotive is 97 tons, of which 70 tons is on the driving wheels. While the rated power is 2200 horsepower, the output can be increased during acceleration of the train to 3000 horsepower.

The Pennsylvania Railroad has installed unusually powerful locomotives for their tunnel service in and around New York City. The starting requirements of these locomotives are unusually severe in that they will be called upon to start a train of 550 tons load on the tunnel grades under the Hudson River, which grades are approximately

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NUMBER 76

PRINCIPLES AND APPLICATIONS OF ELECTRICITY

PART IV

ELECTRIC LIGHTING

CONTENTS

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CHAPTER I

ARC LAMP LIGHTING

Electric lighting has progressed with wonderful rapidity during the last two or three decades. Totally distinct systems have become merged into one, and power transmission has become a stepping stone to electric lighting proper, alternating currents being transmitted and converted into direct currents without difficulty. In fact, the greatest operating systems found in New York and other large cities in the United States combine high-pressure alternating power transmission with low-pressure direct-current distributing systems.

One of the earliest investigators of electric light was Sir Humphrey Davy, who in 1810 produced the first electric arc of any magnitude. During the middle of the last century considerable experimenting was done for producing a satisfactory arc lamp, but the attempts were not successful, chiefly on account of the lack of a satisfactory source of electricity, the battery being the only source of power. The invention of the Gramme dynamo in 1870 made new investigations and inventions possible. The Jablochkoff electric light was first introduced in 1876, and from this time the development of electric light has been very rapid. The incandescent lamp was used merely as a laboratory apparatus up to 1878, when a lamp was produced consisting of a platinum spiral in a vacuum. The first successful carbon filament lamp was made in 1879.

Electric lighting may be done either with an alternating or a direct current. Often an alternating current is used for the transmission lines, and is converted into a direct current at the point of distribution. There is no essential difference as far as the lamps and lighting are concerned, the sole difference being in the power plant and distribution. For smaller systems a direct current generator is often employed. The lighting may be done by means of a constant-current or by means of a constant-potential system. Dynamos suitable for the generation of these currents are termed constant-current and constant-potential dynamos, respectively. Constant-current dynamos are designed for the purpose of supplying energy to arc lamps, and constant-potential dynamos for the purpose of supplying energy to incandescent lamps.

Arc Lamps

The light in arc lamps is produced by two carbon rods which are connected in an electric circuit so that the circuit is closed by the contact of the tips of the carbon rods. When after such contact the carbon rods are again separated, the electric circuit is not broken if the space between the carbons is not made too great, and an arc of light will be

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formed between the two points. The light emitted is due to the intense heat of the tips of the carbon rods, and also, to a smaller degree, to the arc itself.

When direct current is used for arc lighting, most of the light is produced by the end of the upper or positive carbon rod, or electrode, which acquires a hollow center known as the crater of the arc, as shown in Fig. 1. This crater, which throws the light downward, has a temperature of from 5,500 to 6,000 degrees F., a temperature that is high enough to vaporize carbon. The lower or negative carbon rod or electrode becomes pointed at the same time as the positive one is hollowed out. The carbons are consumed by the passage of the current, the positive electrode being reduced in size about twice as fast as the negative.

When an alternating current is used for arc lamps the upper carbon becomes alternately the positive and the negative electrode, and in this case no crater is formed; but both electrodes become pointed and the

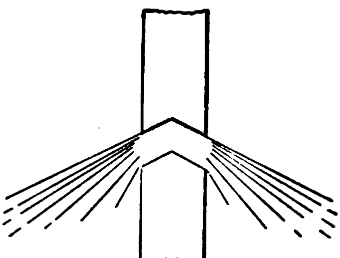

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Fig. 1. Crater of Arc Lamp Carbon

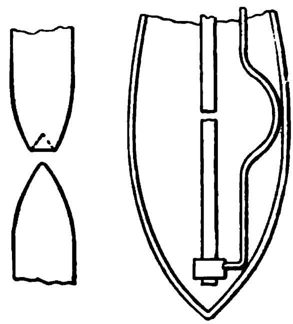

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Fig. 2. Carbons Burning in Air and Enclosed in Globe

two electrodes give off about the same amount of light and are consumed with about the same rapidity. The great illuminating property of the crater in the direct-current arc, however, is lost, and the light given out by the alternating current arc is thrown upwards as much as downwards, which makes it necessary to use a reflector in order to take advantage of the full effect of the light produced.

Requirements in the Operation of Arc Lamps

It is evident that as the carbon rods are consumed, some arrangement must be provided for maintaining the tips at the proper distance apart, so that the current can flow continually without interruption. The mechanism for maintaining the distance between the carbons must be automatic, and must perform four distinct functions, as follows:

1.—The carbons should be in contact or be brought into contact when the current begins to flow through the lamp for the production of light.

2.—Immediately after the current has commenced to flow, the carbon rods should be separated a certain distance for forming an arc of light between the points.

3.—The carbon rods should be fed forward at the same rate as that at which they are consumed.

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4.—When the carbons are entirely consumed, the circuit should be either opened or closed, according to the manner of power distribution used.

There are a number of different mechanisms used for producing the results desired. They all depend upon the action of a solenoid—that is, a soft iron core enclosed in and magnetized by a coil of wire through which an electric current flows—which acts against the force of gravity or against springs. In one type of mechanism, called the shunt-lamp type, the carbons are held apart until the current is turned on, and a solenoid is connected across the gap thus formed. When the current is turned on, it passes first through the solenoid coil, and the plunger or core of the solenoid forces the carbons together, thus starting the arc. The springs are so adjusted in relation to the pull of the solenoid that the carbons are separated again and the arc maintained at its proper length.

In another type called the series-lamp mechanism, the carbons are in contact when the current is turned on, and the current, flowing through a pair of solenoid coils in series, separates them immediately, thus producing the arc. The distance between the carbon electrodes is maintained by the fact that when the arc becomes too long, the resistance to the current is increased so that the strength of the current is lowered, and the pull on the solenoid weakened. Thus the carbons will feed automatically together by gravity until equilibrium is again established.

In a third type of mechanism, called the differential type, a combination of the two previously mentioned types is used. The carbons are in contact when the current is turned on, and series coils are used for separating them, while a shunt coil of the same type as used in the shunt lamp, and which is connected across the arc, prevents the electrodes from being pulled too far apart.

The mechanical methods used for securing and feeding the carbons may be divided into two classes, known as the rod feed and the carbon feed. In the rod-feed type of lamp the upper carbon electrode is supported by a metal rod, to which the regulating mechanism is attached. The current is fed to this rod by means of a sliding contact. In the carbon-feed lamps the controlling mechanism is connected directly to the carbon by means of a kind of releasing clutch which grips the carbon when it is to be lifted, but releases its grip when the tension is released.

Types of Arc Lamps

An early type of lamp, called the double carbon lamp, employed two pairs of carbons which were used for the purpose of increasing the life of the lamp. In this type the two sets of carbons were so arranged that when one pair of the carbon rods was consumed, the other pair went into action. Later improvements in arc lamp construction have made this type obsolete. The old type of arc lamp consumed about 10 amperes at 50 volts. The new type, with a closed globe, as shown in Fig. 2, takes about 12 amperes at 80 volts. The older type was built

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with the carbons burning in the air, while the newer and improved type has them enclosed in a small globe supplied with a valve. When the oxygen in the air is consumed inside of this globe, only carbon monoxide and nitrogen remain, which are perfectly neutral gases as far as combustion is concerned. The result is that there is no further oxidation of the carbons, and the period of their usefulness is increased from the 8 or 10 hours common in the older designs to from 100 to 150 hours in the most improved designs. The increase in power required through the introduction of the later type is counterbalanced, in a financial sense, by the saving in labor in renovating the carbons, and, to some extent, by the saving in the carbons themselves, although, as we shall presently see, some of these advantages are offset to a serious degree by other considerations, and, in some respects, at least, the advantages are more apparent than real.

The Enclosed Type of Arc Lamp

In the enclosed type of arc lamp the access of air is restricted, as already mentioned, and in consequence of this all the oxygen contained in the enclosure is consumed shortly after the arc is struck and the contents within the enclosure is converted into carbon monoxide gas which is unable to support further combustion. The carbons then slowly volatilize, and the arc is maintained across the heated carbon vapor. The enclosure, however, is not made fully air-tight, as such an arrangement would be difficult to maintain, but the access of air is carefully restricted. Owing to the fact that there is practically no burning of the carbons, a much longer arc can be employed than that used in the open type, and hence a correspondingly higher difference of potential between the lamp terminals. The carbons remain practically flat at the ends instead of acquiring the pointed negative and coned positive electrode shape found in the open type.

For a given power, however, the enclosed type of lamp gives rather less light than the open form, and while the carbons last much longer, it must be remembered that only carbons of the best quality can be used for enclosed arc lamps. Cheaper carbons, such as would give good results in an open lamp, cannot be used for the enclosed type, because it is found that after a few hours' run, a thick white coating, consisting chiefly of silica, deposits itself over the inner surface of the enclosing glass covering, and this coating absorbs a large proportion of the light. Hence a more expensive carbon must be used, so that the saving in the actual cost of carbons is not as great as might be expected, while, of course, the cost of attention and trimming is largely reduced.

Due to the fact, however, that the carbons last so much longer in the enclosed type of lamp, there is a tendency to neglect the lamps until they require fresh carbons, and when the globes become coated with more or less thickly deposited silica, a considerable amount of the light is absorbed, so that the efficiency of the lamps is reduced. To avoid this the globes must be regularly cleaned, and this, in effect, reduces materially one of the chief advantages of the enclosed arc, as it takes nearly as much time to properly clean the globes as it would to replace

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the carbons. The direct-current open type arc lamp also burns very steadily when once a proper crater has been formed, but the enclosed lamp has a rather unsteady arc which wanders around the edges and over the faces of the carbon ends; hence in many cases the inner and outer enclosing globes are made of opalescent glass, especially when a steady light is essential. The advantage of not having to replace carbons except at long intervals, and the consequent elimination of the risk of the lamps going out frequently because of burnt out carbons, constitutes, however, a more valuable feature than these defects, and the enclosed arc lamp has practically superseded older forms.

When the current running through an arc lamp is increased beyond a certain value for any given size of carbons, or when the arc of the lamp is reduced beyond a certain point, a peculiar hissing noise is heard, and the light produced is materially diminished. The hissing continues more or less irregularly until the length of the arc has been

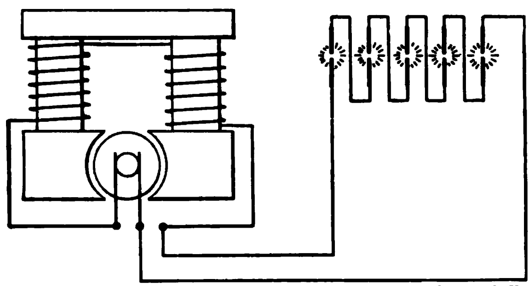

Fig. 3. Arc Lamps Connected in Series

re-established or the current diminished. In direct-current lamps, the positive carbon is frequently made with a core of softer carbon having a lower specific resistance. This assists in the formation of a good crater and thus is conducive to steadier and better burning of the lamp.

Current Supply for Arc Lamps

Arc lamps can, as already mentioned, operate either by direct current or alternating current and may be connected either in series or in multiple. There are, of course, still a great many open lamps used, but almost all lamps used in connection with alternating current or in connection with constant-potential direct current, are of the enclosed type.

The open arc lamps are always connected in series, the current being usually produced by a constant-current dynamo which is series-wound so that the current developed in the armature passes through the outside series circuit and then through the field windings back to the armature again. The illustration Fig. 3 clearly shows the simple character of this system. In the series system of electric lighting each arc lamp requires a certain current and pressure in order to give the candle power expected.

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The arc lamps for constant-potential direct-current systems are similar to those used for direct-current series systems, but must be provided with a resistance connected in series with them. By this means the voltage of the arc is kept at its required value. The lamps for alternating-current circuits are similar in construction to those for direct currents, although they differ in some details. Arc lamps are made which can be adjusted so as to operate either on direct or alternating current and also at varying voltages.

When the electric current is produced by an alternator it may, as mentioned, either be used directly as an alternating current in the arc lamps or be converted into a direct current. When a constant-current dynamo is used for the production of the electric current, some regulation becomes necessary, and the methods used for this purpose will be explained in the following.

Constant Current Regulation

The regulation of a series dynamo connected to a series circuit requires a method by which the dynamo is capable of automatically increasing or decreasing its difference of potential as the number of lamps are increased or decreased in its circuit. If, for instance, 20 lamps of the older type were employed, each lamp requiring 50 volts and 10 amperes, a current of 10 amperes and 1,000 volts must be sustained, and the dynamo is required to automatically regulate its voltage and current if one-half or one-quarter of the lamps are cut off. This means that if 10 lamps are on the circuit 500 volts only are needed, 15 lamps, 750 volts, etc., as under all these circumstances of change the 10 amperes remain constant. The problem is that of a circuit in which, with every increase of resistance, an increase of voltage must take place. The means employed for the regulation of the voltage of a dynamo can be classified under the following heads: Increasing or decreasing the speed, increasing or decreasing the lines of force, and increasing or decreasing the armature conductors.

It is quite evident that it is not practical to attempt to change the speed to suit each particular voltage. The other two methods given have, however, been successfully carried out. The varying of the magnetic field is done by means of a resistance placed across the terminals of the field winding, so controlled by automatic means that when greater voltage is required, this resistance is increased, and when less voltage is required, the resistance is cut down.

Shunting the Field

The theory on which the method of changing the field strength is based, is as follows: If greater voltage is required of the dynamo, it can be generated if more lines of force are supplied to the rotating conductors. If an electro-magnet is placed in series with the outside circuit, a temporary increase or diminution of current caused for an instant by the lamps being increased or decreased in number, will make the coil a stronger or weaker electro-magnet. If the coil attracts a core of soft iron, which is attached by the proper mechanism to a pair

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of carbons dipping into water, as shown in Fig. 4, and if the mechanism operates in such a manner that when the magnet is strengthened the carbons dip deeper, and when the magnet is weaker the carbons are lifted out, then the object is accomplished of weakening the field strength by shunting the fields when the pressure is too high outside, and increasing the field strength by lifting the carbons out when the outside pressure is too low. Tracing the circuits will show that the carbon rods dipping into the water offer a resistance which is greater or less across the field terminals according to the strength of the current in the main circuit. When the carbons dip deeply, current from the field passes through in such strength that the ampere turns are cut down and a smaller voltage is generated. When the carbons are lifted, less current passes through this liquid rheostat and more through the fields. In other words, the arrangement represents an adjustable resistance. The method outlined is theoretically correct, but the difficulty of adjusting the carbon rods and the resistance caused it to be superseded by the method described below, where the regulation is effected by shifting the dynamo brushes.

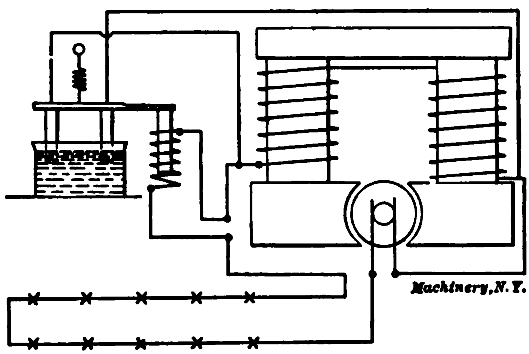

Fig. 4. Arrangement for Shunting the Field

The conductors of an armature can only give out their full electromotive force if the brushes on the commutator are properly adjusted for collecting it. There are points on the commutator where a pair of brushes can collect the maximum and minimum pressure. This is readily discovered in an ordinary shunt dynamo where the shifting of the brushes to different parts of the commutator increases or lowers the pressure a great many volts. Examination of the armature winding discloses the fact that the commutator is so connected to its conductor that the brushes can take off the pressure at a point where the electromotive force is low as well as at a point where it is high. In fact, between points 90 degrees apart from each other, the commutator can give the highest and lowest pressure of the armature. Hence a cutting down or raising up of the armature difference of potential can be accomplished by moving the rocker arm of the dynamo to which the brushes are attached either by hand or automatically. In arc light practice it is accomplished automatically by means of an electro-magnet

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connected to the main circuit, as shown in Fig. 5. The current passing through the string of arc lamps actuates this coil and through it the core which it energizes. The core is so arranged that it moves the rocker arm of the dynamo according to the pull exercised upon it by the electro-magnet. If the current in the magnet is very great, the rocker arm is pulled over quite a distance, and in consequence the brushes take the pressure from different points of the commutator. When the magnet is not pulling very hard, the current in the main circuit is normal, that is to say, an adjustment has taken place between the resistance represented by the arc lamps and the voltage supplied to the line by the dynamo. This continuous adjustment is only brought about effectually by means of an electro-magnet sensitive to a rise or fall of the normal current and its consequent reaction upon the position of the brushes through the medium of the rocker arm.

Pressures as high as 6,000 volts have been used in high-tension direct-current lighting. The character of the current is pulsating, the throb

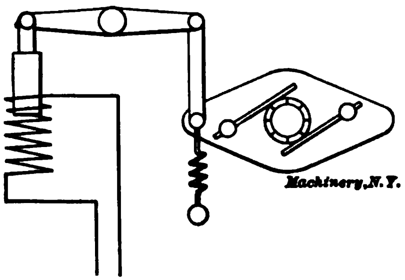

Fig. 5. Automatic Adjustment of Commutator Brushes

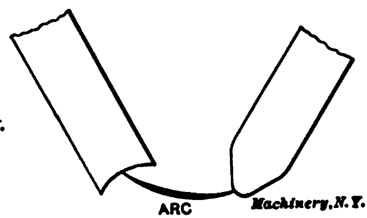

Fig. 6. Arrangement of Carbons in Flaming Arc Lamps

or pulsation being very effective in keeping the high-tension arc lamp mechanism in good adjustment. The candle power of arc lamps may be rated as either spherical or horizontal. The spherical candle power is the amount of light distributed on all sides of the arc. Light measured on a horizontal plane is the effective candle power produced. Means are employed to reflect as much of the light as possible downward, and thus increase the effectiveness of the lamp as a source of illumination. In arc lamps used on alternating current circuits a reflector is necessary on account of the constant reversal of the arc. During one alternation the crater of the carbon is above, during the next below. The result of this is the continuous shifting of the light upward and downward and hence the necessity for a reflecting device of some descripion to preserve a uniformity in the degree of horizontal illumination.

Flaming Arc Lamps

If metallic salts which readily volatilize at a relatively low temperature are added to a hollow or cored carbon, having a metal strip for a core, the character of the arc produced between the electrodes of an arc lamp is changed to a marked degree. The metallic vapor between the terminals lowers the resistance between the electrodes, and hence a

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longer arc is made possible, the character of which is such as to produce considerably more light per watt than that of the ordinary arc lamp. Lamps of this type are called flaming arc lamps. It is claimed by the manufacturers of these lamps that one flaming arc lamp is sufficient to replace five regular enclosed arc lamps. In order to fully appreciate the illuminating qualities of the flaming arc lamps, the following comparison of the watts required per candle power by different kinds of lamps may be of interest. .

	Watts per Candle Power
Carbon filament incandescent lamps..................	3.1 to 4.0
Tungsten filament incandescent lamps................	1.2 to 1.5
Enclosed arc lamps..................................	1.0 to 2.1
Flaming arc lamps...................................	0.25

These figures are subject to modification, but will be found accurate for average conditions. The tantalum lamp consumes from 2 to 2.5 watts per candle power, and therefore occupies a place between the carbon filament and the tungsten lamp, the latter being, in regard to economy of current, the closest competitor of the arc lamp of all the incandescent lamps.

The mechanism of flaming arc lamps has been modified to meet certain requirements which they present. It has been found impracticable to operate electrodes containing metallic salts one above the other, hence the established practice is to have both electrodes pointing down in an inclined direction, and so arranged that they converge to a point where the arc is struck. (See Fig. 6.) As no obstructions are below the arc, this further increases the efficiency, does away with all shadows, and gives a most excellent distribution of the light.

In some cases where the regular arrangement of the carbon has been retained, the lower carbon is made heavier, is saturated with the metallic salts, and on direct-current circuits is used as the positive carbon. The light is thrown down by means of a small reflector surrounding the upper carbon.

Flaming arc lamps burn either two in series on a 110-volt circuit or four in series on a 220-volt circuit. Because of the liability of one lamp in a series going out and thus affecting the circuit, a device is added to each lamp so that a defect in one lamp will not open the circuit and thereby interrupt the other lamps in the same series. To accomplish this, an extra resistance is supplied which is equal to the normal voltage drop at the arc, which is automatically inserted when the arc fails and thus keeps the circuit closed.

Cost of Operation of Flaming Arc Lamps

While the flaming arc lamp is of high efficiency and in many respects, from a light standpoint, possesses advantages over practically all other types of lamps, it should not be assumed that flame lamps may be indiscriminately installed, and always give economical results, due especially to the fact that carbons for flaming arc lamps are very much more expensive than ordinary arc lamp carbons. Each case must be

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investigated on its own merits, and in general flame lamps will be found more economical in ultimate cost where large areas are to be lighted or where smoke, dust or vapor is present.

In order to obtain a correct conception of the economical advantages of the use of flaming arc lamps, a concrete example may be analyzed. Assume that 40 flaming arc lamps are used to replace 200 enclosed lamps. Assume further that current costs 2 cents per kilowatt-hour, and that the enclosed arc lamps consume 132,000 kilowatt-hours per year, while the flaming arc lamps consume but 26,400 kilowatt-hours. The saving in current, then, would equal 105,600 kilowatt-hours, equivalent to a value of $2,112.

The labor of trimming would be about equal, as the flame lamps require trimming five times as often, but only one-fifth as many are used. The carbon expense would be increased by $1,540, but repairs and other items of expense would be but one-fifth of those for the enclosed lamps. A clear saving is thus shown, even at the very low cost of current assumed, and the saving would be greater where current costs more. Further, the saving on the power plant would in many cases be a feature of predominating importance, as that amount of power could be utilized for other purposes.

A considerable saving is also made possible in new installations through the far less extensive system of wiring required, due to the fewer lamps used to give an equal illumination. The same applies also to the size of the power plant, which can be proportionately less when flaming arc lamps are installed. The purposes for which these lamps are especially adapted are for the lighting of shops and factories, street lighting, dock lighting, and under certain conditions, for store lighting.

The disadvantages of the flaming arc lamp are that the carbons are expensive, require frequent renewal, as compared with the enclosed type of arc lamp, and that the globe becomes coated on the inside with a deposit, which requires frequent cleaning. As regards the life of the carbon, the maximum is given as 24 hours, with carbons 16 inches long.

Flaming arc lamps of ordinary size give from 3,000 to 4,500 candle power.

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CHAPTER II

INCANDESCENT LIGHTING

Lighting by means of incandescent lamps is by far the most common type of electric lighting used. The current for the lamps may be either alternating or direct current. In a direct-current system the dynamo employed may be either shunt- or compound-wound. When electric lighting is conducted on a large scale, as in the case of stations which supply an entire city with electricity for light as well as for power, low-tension direct-current lighting is commonly combined with a high-tension two- or three-phase alternating current distributing system. This latter system is employed in order to increase the economy of transmission to points more or less distant from the original generating plant.

The Incandescent Lamp

The incandescent lamp is based upon the principle that when an electric current is sent through a conductor of high resistance, the conductor is heated. If the current, material for the conductor, and other conditions are such that the conductor will be heated until it becomes incandescent and hence gives out light, this combination embodies the principle of the incandescent electric lamp. The material for the conductor in ordinary lamps is carbon, which is formed into a small thread called the filament. Some lately developed lamps employ metallic filaments, and these lamps will be referred to in a later chapter. Carbon filament lamps, however, are as yet the most commonly used, the carbon having been selected for two reasons. In the first place, it is capable of standing the very high temperature required, or about 2,350 degrees F. In the second place, as a conductor of electricity it presents the required resistance, which in an incandescent lamp varies from 150 to 200 ohms. In addition, it does not deteriorate too rapidly when in use.

There are three features relating to the incandescent lamp which are of importance in connection with its use. These are the life, candle-power and efficiency of the lamp. The average life of an ordinary 16 candle-power lamp is from 600 to 800 hours. By efficiency of an incandescent lamp is meant the power in watts required per candle-power. This efficiency generally has a value between 3 and 4. In other words, a 16 candle-power lamp will consume anywhere from 16 times 3 to 16 times 4 watts to produce its light. Experience has taught that any increase in the normal candle-power, or decrease in the power consumed, is only gained at the expense of the life of the lamp. Regulation, as it is called, that is to say, the preservation of a uniform potential in the entire system of electric lighting is, therefore, necessary if any relationship is to be kept between the light produced, the power consumed

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in producing it, and the life of the lamp. A fall of a few volts in the generator means a reduction of between 20 and 30 per cent in the candle-power of the lamps. A rise of a few volts will send so much more current through the lamps and so increase the candle-power that the life or durability of the lamps is reduced. The great increase in current with an increase of only a few volts is due to the lowering of the resistance of the carbon as its temperature rises. A hot carbon conducts much better than one that is cold, and when, as in the case of a carbon lamp filament, incandescence is reached, it becomes very sensitive to a slight increase in pressure.

Power Consumption and Life of Lamp

The two factors, power consumption and life of lamp, are very closely associated. In the 500th hour of the life of the lamp, it usually will begin to grow dim and then either new lamps or a higher voltage would be required. If a higher voltage is sent over the line the power consumption becomes very much greater. For instance, with 1,000 lamps, each requiring 50 watts, a total of 50,000 watts would be required when the lamps are new. But if the same lamps should give the same amount of light after they have commenced to grow dim, the power per lamp would rise to, say 64 watts, and a total of 64,000 would be required; the difference, 14,000 watts, represents such an increased cost in the production of electricity that it would become more expensive than lamp renewals. Again, if the voltage is not increased, the lamps will burn very dimly, and instead of giving 16 candle-powers, the light would be only about 12 candle-powers or thereabouts; thus equal power would be consumed at the plant for producing only 75 per cent of the light, which, of course, would be poor practice. Hence it will be understood that there is a certain point in the life of the lamp when it is more economical to replace the lamp with a new one than to continue to use the old one with its decreased candle-power. A decrease of about 80 per cent in the candle-power is commonly assumed to indicate the point at which the lamp ought to be replaced.

As regards the influence of the voltage on the life of the lamp, the following figures may be of interest. An increase of about 3 per cent in the voltage reduces the life of lamp by about one-half, while an increase of only 6 per cent causes the useful life of the lamp to fall to only one-third of its value at the normal voltage; hence it is evident that it is of extreme importance that the voltage of the current sent into the line remains at a definite point, so that there will be neither a variation in the lighting properties of the lamps nor a decrease in the length of life of the lamps.

The voltage ordinarily used for incandescent lamps depends to some extent on the method of distribution of the power. Ordinarily 110 or 220 volts pressure is used. When the higher voltage mentioned is employed, the filaments should be long and slender and lamps of less than 16 candle-power should not be used. The selection of lamps depends to a considerable extent upon their efficiency. Lamps of an efficiency of [illegible] that is, lamps taking about 3 watts per candle-power, require

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that the voltage be very carefully regulated at a constant value. Lamps taking 3.5 watts per candle-power permit a variation of 2 per cent from the maximum voltage, and when the voltage regulation is poor, lamps of an efficiency of 4 should be employed. The values mentioned are for lamps on 110-volt circuits; 220-volt lamps should be given a lower efficiency in order to obtain a longer life.

Regulation of Shunt- and Compound-wound Dynamos

The machines best suited to the service of supplying an incandescent system with its energy are the shunt- and compound-wound direct-current dynamos. It is most common to use compound-wound generators for smaller private installations, because in this case the dynamo is practically automatic in its action, which means that between no load and full load—the minimum and maximum of lights—it will preserve a comparatively uniform pressure. On the other hand, if a shunt-

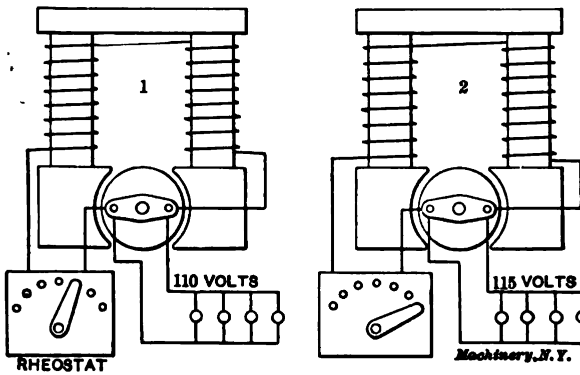

Fig. 7. Effect of Change in Resistance on Voltage

wound dynamo is installed, every important change in the number of lights will necessitate an adjustment of the resistance inserted in the field or shunt winding, in order that the voltage may remain constant, which, as already mentioned, is very important. When the various consumers of the current turn their lamps on or off, the dynamo, sensitive to such changes, will vary its terminal or brush pressure. Constant attention is, therefore, required to preserve a uniform potential by decreasing or diminishing the current in the shunt winding, which is done by means of a rheostat and the consequent throwing in or out of more or less resistance. The effect of this is indicated in a diagrammatical way in Fig. 7.

It is evident that when the current in the windings of the field is increased by cutting down the resistance in the rheostat, the current in amperes, and hence, the ampere-turns of the field winding increase. The lines of force of the field increase, as does also the electromotive force generated by the dynamo. The reverse happens when the resistance in the field winding is increased. The smaller the shunt-wound generator is, the more constant attention must be paid to this regula-

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tion by means of the rheostat. If the consumption of current is very large, as, for instance, in a large city, where the station load may reach over 200,000 amperes, then the use of shunt-wound generators with rheostat regulation is considered as good practice. In this case station assistants are always at the rheostats to meet the rising or falling tide of the demand for electricity with a resistance adjusted to preserve the constant potential or voltage of the system. Contrary to expectations, this is a very reliable method of regulation, and meets every requirement.

Elements of a Small Electric Light Plant

The essentials of a small private electric lighting plant include as mechanical details boiler and engine with accessories, and as electrical details the dynamo, switchboard and wiring. The switchboard, in

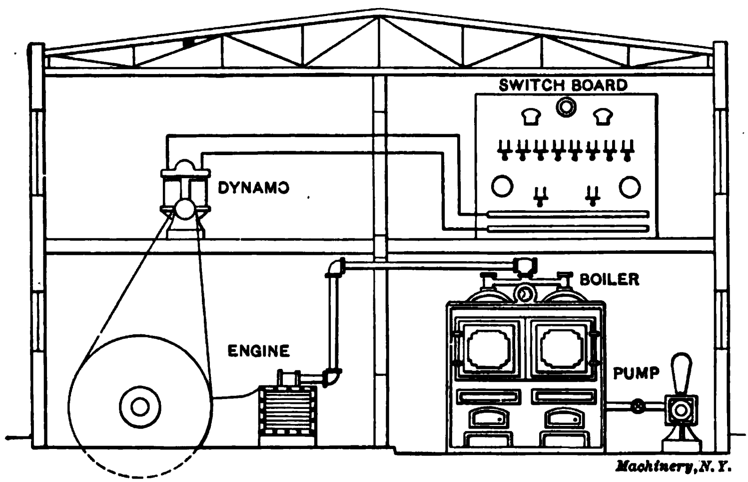

Fig. 8. Essential Parts of a Small Electric Light Plant

turn, contains the ordinary meters required, circuit breakers, lightning arresters, ground detectors, etc. The dynamo has been described in detail in Part III of this treatise, MACHINERY'S Reference Series No. 75. The switchboard and the instruments used on it are described in detail in MACHINERY'S Reference Series No. 78, "Principles and Applications of Electricity. Part VI, Power Transmission." The switchboard performs three functions: it receives the main wires from the generator or generators, and distributes or feeds the current thus received to the various circuits, and in addition it measures the current both as regards its voltage and its strength in amperes. The essential parts of a small electric plant are shown in Fig. 8, the boiler with its feed pump being indicated to the right on the lower floor, the engine to the left, and the dynamo and switchboard on the upper floor. In Fig. 9 is shown the essential parts of a switchboard, consisting of three panels called feeder panel, meter or load panel, and generator panel, respectively. On this switchboard are indicated the various switches and meters.

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A necessary adjunct to the installation is the lightning arrester. Central stations as well as private plants are subjected to the influence of lightning or electrical storms, and it is necessary that the electrostatic discharge is led to the earth before it reaches the generator and causes damage to the machinery. The elementary principle of the lightning arrester is indicated in Fig. 10. It is provided with either an air gap, or a very high resistance path, leading to the earth. This

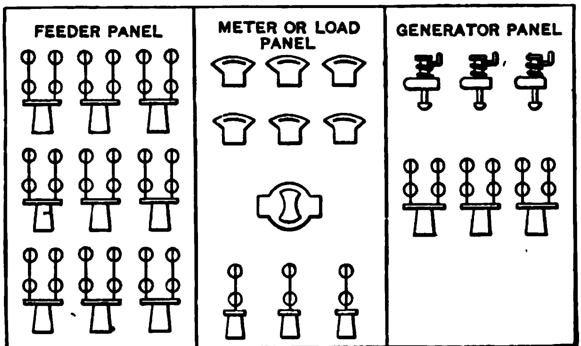

Fig. 9. Essential Parts of Switchboard

air gap does not permit the regular line current to jump across, but the lightning discharge will jump across, owing to its high potential. In order to prevent an arc from being established across the air gap, through which the regular current would find its way to the ground after the lightning discharge has taken place and started the arc, a

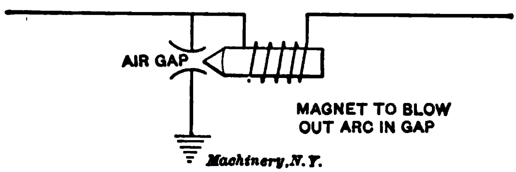

Fig. 10. Principle of Lightning Arrester

magnetic blow-out is provided, which extinguishes the arc. The electrostatic discharges due to lightning are dangerous because they tend to break down the insulation and thus cause grounds and short circuits.

Systems of Distribution

While the series system of distribution of current may be used for incandescent lighting systems the same as it is used for arc-light circuits, as described in the previous chapter, the most commonly used systems for incandescent lighting are the multiple or parallel systems of distribution. In these systems the lamps are connected across the lines leading to the central station or to the sub-station where the current is transformed or converted, as indicated in Figs. 11 to 13.

The most serious difficulty which has to be overcome in the multiple systems of lighting is due to the fact that the flow of current in a

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conductor is always accompanied by a fall of the voltage due to the resistance of the conductor, so that the lamps at the end of the system will not have the same voltage impressed upon them as those nearer the source of the current. Various schemes have been worked out in order to overcome this difficulty. These methods may be classified as follows:

Parallel feeding, conical conductors.

Anti-parallel feeding, cylindrical conductors.

Anti-parallel feeding, conical conductors.

If parallel feeding and cylindrical conductors (Fig. 11) are used, it is evident that the voltage becomes a minimum at the lamps at the end of the line. When a conical or tapering conductor is used, that is, a conductor having its diameter so proportioned throughout its length that the current divided by the cross section of the conductor is a constant, the difficulty is partly overcome. The constant (current ÷ cross section of conductor) is called current density. In practice,

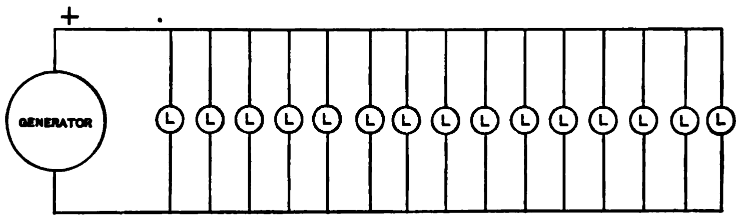

Fig.11

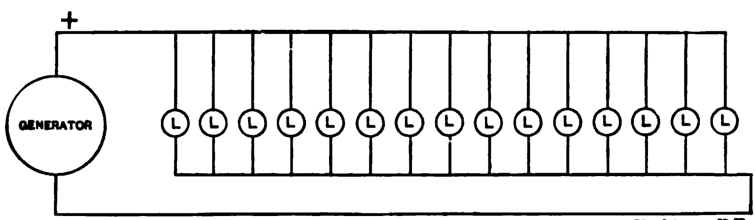

Fig.12 Machinery,N.Y.

Figs. 11 and 12. Systems of Distribution of Lighting Current

conical conductors consist of lines having smaller diameter wires in the circuit as the current becomes less. In the anti-parallel systems (Fig. 12) the current is fed to the lamps from opposite ends of the system, so that a balanced condition is thus obtained.

Two- or Three-wire Systems

The two-wire system is simply the ordinary system indicated in Fig. 11, where the current passes out through one wire and returns through the other. A commonly used system, however, employs three wires for the circuit, and in some cases even five. In the three-wire system, three conductors are used as shown in Fig. 13. As indicated, this system dispenses with one wire, connecting two dynamos on three wires instead of on four. The positive pole of one dynamo is con-

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nected to the outer wire, and the negative pole to the middle wire. The negative pole of the other dynamo is connected to the other outer wire, and the positive pole to the middle wire. This, in effect, gives two dynamos in series, the middle wire being called the neutral wire. The other two wires, one on each side of it, are respectively the posi-

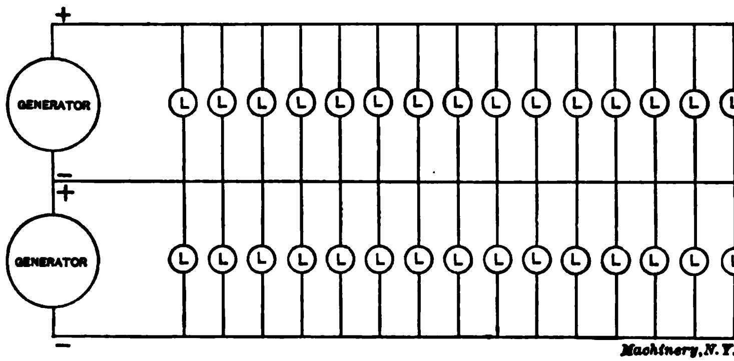

Fig. 13. Three-wire System of Distribution

tive and negative wires, as shown in Fig. 13. These wires are also frequently called the outer legs of the system. The general arrangement of the connections at the dynamos is indicated in Fig. 14.

Advantages of the Three-wire System

The advantages of the three-wire system are found in the saving of copper, and the increased flexibility of the system through the use of different voltage for lamps and for motors also fed with current from

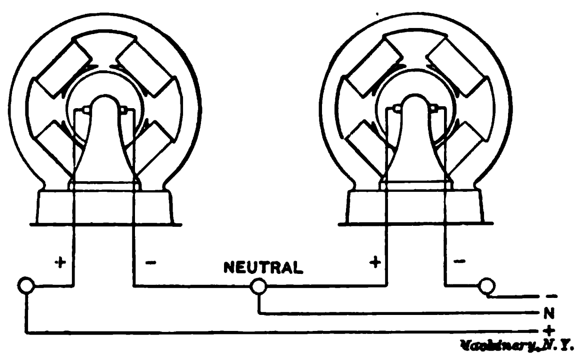

Fig. 14. Connections at the Dynamo for Three-wire System

the same supply. Between the middle or neutral wire and the outer leg on either side may be found a pressure of about 110 volts. Between the two outer wires double this pressure, or 220 volts, is on tap for motor service, although it is not good practice to feed motors directly from a lighting circuit. Take the case of 50 lamps taking ½ ampere apiece, fed respectively by a two- and a three-wire system for purposes of comparison. On this basis 50 lamps require 25 amperes, and a two-wire system would have to supply a wire of sufficient cross-section in

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circular mils to carry this current with the small loss in pressure expected. The formula for this size of wire is given as follows:

$$\text{Circular mils} = \frac{\text{number of feet of wire} \times \text{amperes} \times 12}{\text{volts drop}}$$

[The area of copper wires is usually given in circular mils. By a circular mil is meant the area of a circle 0.001 inch in diameter. Square mils are sometimes used for expressing areas. A square mil is the area of a square whose side measures 0.001 inch. One square mil equals 1.27 circular mil. The diameters of copper wires used as conductors are usually given in the American or Brown & Sharpe wire gage.]

If in the above case the circuit is 100 feet in length and a drop of 2 volts is allowed in the wire, then the calculation will give

$$\text{Circular mils} = \frac{200 \times 25 \times 12}{2} = 30{,}000.$$

If the two-wire system calls for a wire of 30,000 circular mils for 50 lamps taking ½ ampere apiece with a 100 foot run and a 2 volt

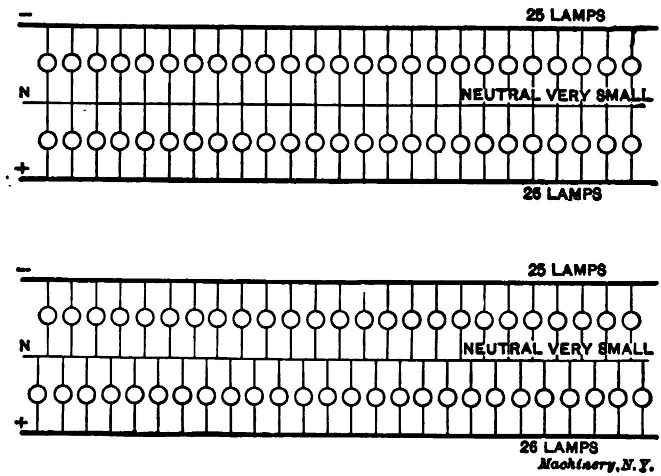

Fig. 15. Examples of Three-wire Systems

drop, calculation will show a smaller wire for a three-wire system of lighting with just as many lamps. In a three-wire system the lighting must be *balanced*, that is to say as many lamps must be placed on one side of the neutral wire as on the other. This will mean 25 lamps on each side of the neutral wire, as indicated in the upper view of Fig. 15, which represents 25 groups of two lamps apiece. The two lamp groups are connected across from the positive to the neutral wire, and from the neutral wire to the negative wire. Examination will show that the 220 volts will send ½ ampere through every two lamps in series. The neutral wire in this case, when the circuit is perfectly balanced, performs no service. If there were 25 lamps on one side of the neutral wire and 26 on the other, as shown in the lower view in

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Fig. 15, then it would carry the current of one lamp, namely ½ ampere. A neutral wire, in a three-wire system, therefore, carries only *the difference* in current between one side of the neutral wire and the other. Consequently, if the circuit is balanced it carries no current at all. This is the case with 50 lamps burning on the three-wire system, and only 12½ amperes are required at 220 volts pressure, which, with the same length of run, 100 feet, and the same drop, 2 volts, according to the formula calls for an area in circular mils of

$$\frac{200 \times 12.5 \times 12}{2} = 15,000.$$

In interior house wiring, for *only* the three-wire system, three wires of this size should be used. This means, in comparison, that the two-wire system would require two 100-foot wires of 30,000 circular mils apiece, and the three-wire system three 100-foot wires of 15,000 circular mils apiece. A 100-foot wire of 60,000 circular mils would represent the equivalent of the first, and a 100-foot wire of 45,000 circular mils

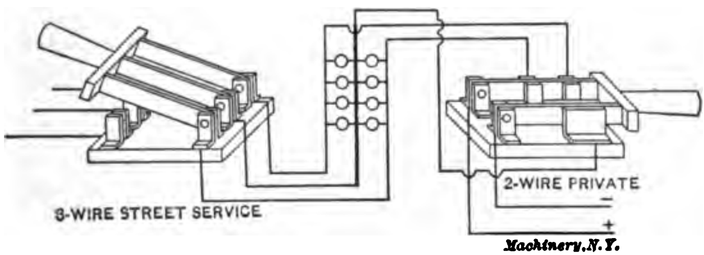

Fig. 16. Switch for Combining Two- and Three-wire Circuits

the equivalent of the second case. The saving would be the difference between 60,000 and 45,000 or 15,000 circular mils, which is 25 per cent. If the neutral wire, as is the case in the system employed in the conduits laid in a city's streets, is not as large as the outer legs, and it is easy to see that it need not be, the saving in copper is much greater, because here, the neutral wire, carrying only the difference in balance between one side of the circuit and the other, can be comparatively very small for balanced circuit. The wiring contractor must see that such a balance exists in planning out the circuits. A certain small difference in balance in the aggregate must of course be taken up by the neutral wire, through consumers turning lights on and off, which makes a perfect balance all of the time an impossibility.

Combination of Two- and Three-wire Circuits

In private houses and public buildings where electric light plants are installed it may become necessary through a break-down of the plant to throw in the street service. A difficulty here presents itself unless the wiring conforms to the system in the street. If it is a simple alternating current system, it may be thrown on without hesitation, provided it is of the same pressure as the lamps require. If the street system is a direct-current three-wire system and the wiring of the building is according to the two-wire system, then the wiring

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must be composite, that is, suited to both a two-wire and three-wire system of lighting. All of this is easily accomplished if the building has been wired according to the three-wire system, only the neutral wire must be of *twice* the cross-section of the two outer legs. It can then be used for either purpose without any change whatsoever. A large double-throw switch is necessary to connect at will the street service or the source of private supply, as shown in Fig. 16.

Losses in Circuits

Wires carrying electricity from point to point dissipate energy to an extent dependent upon the current they carry and their resistance. This waste of power appears in the form of heat. An incandescent lamp is a good illustration of this when in use. The resistance of its carbon filament is sufficiently great with the current passing through it to raise it to incandescence. In the same manner, although not to the same extent, a conductor is heated by the energy it contains, and a certain percentage of power disappears. This can be regarded in two ways: first, as caused by lost voltage or drop, and second, as due to the energy wasted as heat. To calculate the first, or the voltage lost, this formula is employed:

Volts lost = amperes in wire × resistance of wire.

If the lost voltage is multiplied by the amperes, the watts wasted in the wire are obtained. Again, the power which generates heat can be calculated by the formula:

Watts wasted in heat = amperes × amperes × resistance of wire.

These two results will be the same, as shown by the following example: Take a wire of 10 ohms resistance carrying 2 amperes, then the volts lost $= 2 \times 10 = 20$ volts, and the watts wasted $= 2 \times 20 = 40$ watts. If the watts wasted in heat are calculated by the other method the result is: watts wasted $= 2 \times 2 \times 10 = 40$, or the same figure in both cases. One is obtained by the product of the drop in volts by the amperes, the other by the square of the amperes by the resistance. As there are 746 watts to a horsepower, the percentage of a horsepower wasted in the conductor can be readily obtained.

Where many lines are in use carrying power, the loss is considerable, particularly when the current is heavy. The loss increases rapidly as the current increases. In the case just stated, if the amperes are raised from 2 to 4 the watts wasted increase from $2 \times 2 \times 10$ to $4 \times 4 \times 10$, equalling respectively 40 and 160 watts, a ratio of 4 to 1 with only twice the current. Therefore, if the resistance of a line remains the same and the current is doubled, tripled or quadrupled, the waste of power is increased 4, 9 and 16 times, respectively. Reducing the current in conductors transmitting electricity for light and power and increasing the pressure is, therefore, the logical consequence. To accomplish this successfully in electric light practice has been one of the most difficult problems. It has been solved by a flexible system of rotary converters, by means of which a high-potential alternating current is changed into a direct current of low poten-

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tial, or by transformers in which the high-potential alternating current is changed into a low-potential current of the same kind.

Transmission and Distribution of Electric Current

The methods and apparatus used for transmission and distribution of electric current are described in detail in MACHINERY'S Reference Series No. 78, "Principles and Applications of Electricity, Part VI, Power Transmission." In the following, therefore, only a brief review of the methods employed will be given. The function of a central station is the generation and distribution of electricity for electric light and power service, but it must operate as well as a power transmission plant in order to distribute its energy with economy over an increasing radius. For this reason it must be equipped with apparatus by means of which it can both distribute electricity at low potential within a considerable radius of itself, and also transmit energy at a high pressure to certain points relatively far removed, and there have that energy undergo a process of transformation to low pressure preparatory to its distribution. The delivery of heavy amounts of

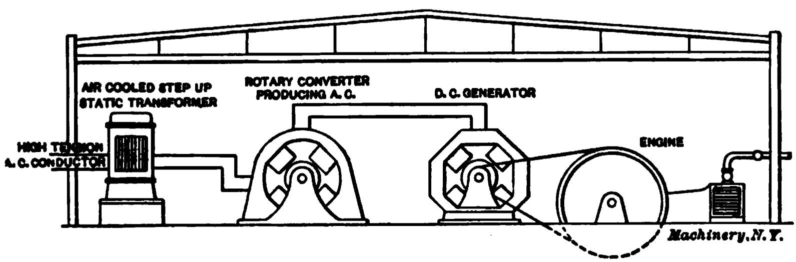

Fig. 17. General Arrangement of Power Station

energy one or more miles away with little loss, thus creating a new center of distribution, is accomplished as follows:

The central station is supplied with two classes of machinery: one, which generates the current at low pressure, continuous and ready for distribution; the other, which transforms it into a high-pressure alternating current for transmission, prior to ultimate distribution at a distance. The low-pressure direct-current generators supply an area in the immediate neighborhood by means of the three-wire system. They also supply energy to rotary converters, which are machines representing a combination of a motor and dynamo in one. On one side the machine receives a low-pressure direct current which operates it as a motor; it gives out an alternating two or three-phase current at a somewhat higher pressure. This result is obtained by means of two armature windings, one of which is for continuous and the other for alternating current. A commutator is connected on one side of the machine to the direct-current winding, and collector rings on the other side to the alternating-current winding.

Not only will a direct current rotate the armature and thus generate on the other side of the machine a two or three-phase alternating current, but if a two or three-phase alternating current, as the machine

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may require, is sent in at the collector rings, the resulting rotation will develop a direct current at the commutator. Thus a rotary converter is capable of taking in a direct current and giving out an alternating current, and, conversely, it can take in an alternating current and give out a direct current. It is for this reason invaluable in the transmission of power.

The alternating current given out by the rotary converter is practically the full equivalent of the energy sent in in the shape of a direct current. This alternating current is received by a transformer, which it enters at a few hundred volts and leaves at a pressure of many thousands, but otherwise still unchanged in character. In this manner, an alternating current of high pressure is sent over transmission lines either underground, in conduits, or overhead, to re-

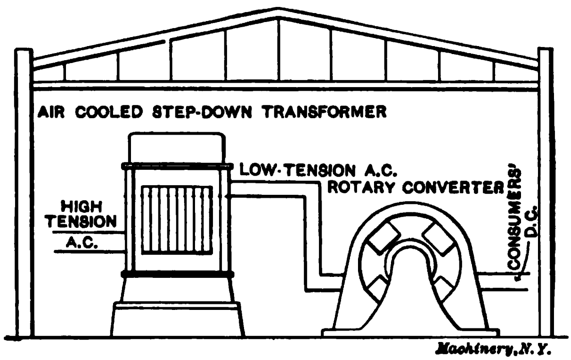

Fig. 18. General Arrangement of Sub-station

inforce distant stations or to create at new points what are called substations. The general arrangement of the power station, with its generator, converter and transformer, is shown in Fig. 17.

The Sub-station

The current, which can be considered, for purposes of illustration, as 5,000-volt three-phase, is now received at the sub-station to undergo a new process of transformation. To outline the previous process in the station itself, it is only necessary to consider a 110 or a 220-volt direct current entering the rotary converter and issuing as a 300 or 500-volt three-phase alternating current. This current is sent into the transformer and emerges at 5,000 volts and goes over the line. In the sub-station are again to be found stationary or static transformers and rotary converters. The power is received in the transformers at 5,000 volts and issues at 300 or 500 volts. It is then directed into the rotary converter, from which it issues as a continuous current of 110 volts and feeds into the three-wire system. The essential details of a sub-station are shown in outline in Fig. 18. The transformers which raise the pressure are called *step-up*, and those which lower it *step-down* transformers.

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CHAPTER III

THE INCANDESCENT LAMP AND ITS MANUFACTURE

Much of the development of electric lighting plants in the United States is directly attributable to the incandescent lamp. Nearly all indoor electric lighting is done by this means. Arc lights are employed almost exclusively for outdoor illumination. The incandescent lamp has passed through a system of evolutionary processes of manufacture, and its origin, first appearance, and the present methods of manufacture will be briefly reviewed in the following.

First Experiments

The heating of a wire in a glass bulb, from which some air had been removed, led to the further experiment of exhausting the bulb still more and noting the increased brilliancy and durability of the wire under these conditions. The glass bulb provided with electrodes connected with a metal wire was first used in laboratory experiments for the purpose of demonstrating the peculiarities of a static charge in a vacuum. The need of an air pump of a better quality than those composed of a cylinder and piston made itself felt, and led to the invention of the mercury vacuum pump. By means of this device, a much higher vacuum than that ordinarily obtained can be secured by letting mercury drop down a tube to which the bulb to be exhausted is attached. Small amounts of air are successively removed in this manner until, by continuing the process, the air pressure in the bulb is reduced to a very small fraction of an atmosphere.

The mercury method of obtaining a good vacuum stimulated inquiry in the inventive field with regard to the incandescent lamp. The first lamp of this type was constructed by Grove, who used a platinum wire inside of a glass bulb and connected it to a number of batteries, thereby raising the wire to a white heat. The vacuum in the bulb served to free the wire from the presence of oxygen and the effects of radiation of heat into the air, which would otherwise be surrounding it. This form of lamp, however, could not be used for commercial purposes, for two reasons. In the first place, it was too expensive, due to the cost of platinum; and, in the second place, the platinum wire filaments could not long resist the high temperature due to the current. In fact, while the light became brighter the more current was sent through the wire, a point was soon reached where the platinum would melt. The experiment, however, of raising platinum wire to a high point of incandescence which gave rise to a brilliant light, although of a temporary and expensive nature, led to further efforts to make a device more permanent as a light producer.

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The name of Edison in the United States and that of Swan in England are closely connected with this stage of the history of the incandescent lamp, and it is curious to note how their experiments in many respects paralleled each other, although the ocean lay between the two laboratories, and great secrecy attended the work of each. The platinum wire proposition was rejected after a while, as was also, for the time being, the hope of using metals or metallic alloys of any description for the filaments. Edison followed the idea that the filament should have a granular structure and be composed of carbon. Swan believed that it should be of homogeneous nature, if its properties were to make it durable. Thus following different lines of investigation, one discovered in bamboo a good material from which, when carbonized, filaments for lamps could be made. The other treated threads with acid, and with subsequent carbonization accomplished equally good results. A patent for a lamp made according to the principles outlined was granted to Edison on January 27, 1880, and read in part as follows:

"An electric lamp for giving light by incandescence, consisting of a filament of carbon of high resistance, made as described and secured to metallic wires as set forth.

"The combination of carbon filaments with a receiver made entirely of glass, and conductors passing through the glass, and from which receiver the air is exhausted for the purpose set forth."

Other lamps containing improvements tending to advance the possibilities of incandescent lighting were invented by Edward Weston, Hiram Maxim and Moses G. Farmer. The introduction by Maxim of the hydro-carbon method of treating the filaments, which will be described in detail later, was one of the most important inventions in lamp manufacture, and is to-day considered as an indispensable element in the success of lamp manufacture.

The use of carbon for a lamp filament was in itself a discovery of no mean importance. It was led up to as a result of conclusions arising from considerations of temperature and vacuum. Metals melt readily at a certain degree of heat. Carbon, on the other hand, is very difficult to soften by heat, and its volatilization takes place in a very slow and limited manner. Carbon is, therefore, especially adapted to fill a unique place in incandescent lighting and possesses the additional advantage that it does not deteriorate at the high temperature to which it is subjected, nor will it become consumed unless air is present. A careful regulation of the current, and of the heat of the carbon, hence constitute the correct working condition.

Another reason why carbon is peculiarly suited for filaments of incandescent lamps is its high resistance, although it is true that the fact that its resistance rapidly lowers with an increasing current is one of the strongest arguments against it. In other respects, however, it was long found incomparably better than metals of any description, although of late metallic filaments have been introduced successfully for incandescent lamp manufacture.

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Filament Manufacture from a Solution

The original methods of making filaments have naturally undergone radical improvement. The bamboo strip is no longer employed, neither is the thread treated with acids, but a semi-liquid or viscous nitro-cellulose solution* has taken the place of nearly all of the former filament bases. This is a product obtained by dissolving cotton wool of good quality in barrels of zinc-chloride solution. This solution is made of a consistency of a syrup, and is utilized for commercial purposes by forcing it through an aperture in a die or plate, from which it issues as a fine thread. The technical term "squirting" is used for this method of manufacture, which has become the generally adopted plan.

The fine continuous thread produced by the squirting process is put into a vessel containing alcohol, in which it is permitted to remain

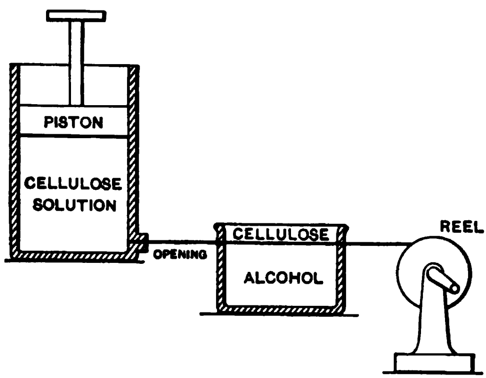

Fig. 19. Graphical Illustration of Filament Manufacture

for twenty-four hours for the purpose of dissolving and thoroughly freeing it from the zinc-chloride solution. When all traces of this solution have been removed, the squirted cotton threads must be freed from the alcohol, which is done by placing them in a sink, and permitting water to run over them for several hours. In this process they expand considerably, and in drying they contract and shrink. Some device must be employed to prevent them from breaking up in drying; one method commonly used is to wind them loosely on drums covered with velvet, so that the threads can sink into the velvet as they dry.

One of the serious difficulties met with in the original zinc-chloride solution of cotton is the presence of air bubbles contained in it, which destroy its uniformity. These are partially removed by agitating or stirring the solution, but this means alone is not sufficiently effective, and it is therefore common to heat the solution in a vacuum retort; this remedy, however, must be most judiciously applied, and the heat regulated, or the solution will suffer permanent injury. Various substances were originally tried for the purpose of making a pure and

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comparatively inexpensive cellulose useful for filament manufacture; they resulted in the ultimate choice of absorbent cotton, a specially picked and prepared as well as readily available foundation.

The filament thread, after being prepared as outlined, is of the general appearance and strength, though of less diameter, than a silk violin E string, or the material used for holding fish hooks to lines. The next step in the process is that of cutting up the material into lengths and of winding these on formers, giving the desired horseshoe shape of the lamp filament. For mere purposes of comparison it may be stated that the most expensive manufactured product in the world is a pound of carbon filaments complete. Hair springs for watches cost less per pound, although it is still the popular idea that in this respect they stand first.

Carbonizing the Filament

The process of carbonization belongs to one of the most delicate processes in connection with incandescent lamp manufacture. Powdered charcoal is used as a bed and covering for the horseshoe lengths of the filaments, and direct contact with the air is carefully prevented during the subsequent heating and cooling period, which occupies close to twenty-four hours.

The oven in which the future filaments are to be carbonized is gradually raised to such a temperature that they all become red hot, this temperature being about 1,000 degrees F. It is evident that the oxygen of the air would rapidly convert the entire mass into ash if permitted to act directly upon it, hence the careful sealing of the crucibles containing the filaments during this process. When removed from the crucible after the process is completed, the filaments are hard and elastic and appear like fine steel wires. It was originally supposed that the carbon of which they are composed is of very fine grain, perfectly homogeneous, and of an average resistance throughout. Tests have shown serious differences between filaments in this respect, however, and individual filaments are not sufficiently uniform in structure to be ready for immediate use. The practice of "flashing," therefore, represents one of the important preliminaries to the final completion of the filament.

After carbonization, but before "flashing," the carbon filaments are mounted or joined to the wires which lead into the glass bulb and which connect the filament with the outside supply of current. These wires are secured in a small glass tube.

The connecting wires, called the leading-in wires, are made of platinum. This metal was chosen because the coefficient of expansion of glass and platinum are about identical. If a metal was used for this purpose which expanded more rapidly than glass, it is quite evident that the glass would crack, air would filter in, and the lamp would be ruined. An equal expansion of glass and leading-in wires thus eliminates this danger. Between these wires and the carbon filament ends a junction must be effected by a cement or conducting material which will withstand the requirements of practice. It was discovered that

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one of the simplest ways of accomplishing this was to hold the platinum and carbon terminals in juxtaposition, and employ either a carbon gas or liquid to supply a deposit at the joint to form the permanent connection. Other ways of making a joint between these two elements are also used, consisting of the electroplating of one to the other, or clamping one around the other, or by means of a cement. Of these methods, the use of a carbonaceous paste, or the effecting of a junction by a carbon deposit, are most generally in use.

The Process of Flashing

A microscopic examination of newly carbonized filaments shows great differences in diameter at various parts of the filament and the presence of open pores. The idea was suggested, therefore, of heating the filament to redness, while exposed to the influence of a gas containing carbon. The advantage of this lies in the fact that the carbon of the

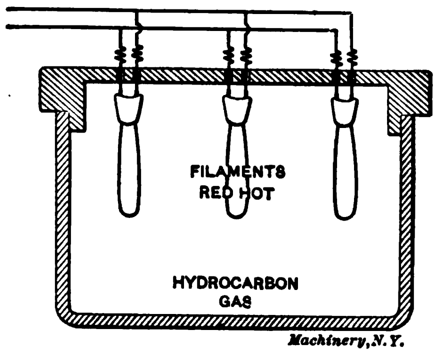

Fig. 20. Flashing the Filaments

gas will be deposited wherever the filament is unduly heated, and otherwise it will form a uniform coating, thus removing the drawbacks noted.

Glass receivers, holding a hydro-carbon gas, such as the vapor of naphtha for instance, are so mounted that the filaments to be exposed to the flashing process can be conveniently inserted and treated, a current being meanwhile sent through them, as shown in Fig. 20. The greater heat at the lesser diameters means a heavier deposit of carbon there than at other points in the filament. The pores fill equally, and the filament when withdrawn assumes a metallic luster and springiness which are regarded as its chief characteristics.

Governing the Resistance of Filaments

Although the flashing process builds up the filament, in the sense that it makes it uniform, the process in itself has the effect of reducing the resistance in total. In other words, discrimination must be exercised in exposing filaments to the current and gas; otherwise the resistances will be so varied that it would be impossible to obtain lamps of equal wattage and candle power. Thicker filaments than others can be kept longer in the gas, and during the flashing, tests of

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amperes and volts will indicate the exact value of the resistance. This cannot be done successfully when the filament is cold, because of its variation in resistance between the two degrees of temperature. The resistance of a 250-ohm filament will drop during the flashing process to 225 or even 212 ohms, and the drop may take place with comparative rapidity unless the current supply is watched carefully. As the filaments before the flashing show great differences in resistance, it is evident that the commercial requirements make this particular phase of the manufacture the most important. The more uniform the ultimate products of the lamp factory, other things being equal, the greater the advantages where efficiency tests for superiority are to be made.

Presence of Foreign Matter and Gases

Volcanic actions seem to fairly represent the general character of the minute, but nevertheless similar class of phenomena, occurring in a filament undergoing flashing. Not only may these eruptions occur at this time, but when the lamp is finished and in use a peculiar yellowish-black coating will collect within the bulb. All of this is the consequence of the presence of gas in the filament, held by pores developed during the carbonizing process. The original cellulose string is uniform in character, and devoid of perforations, cracks or pores. But the continued heating yields defects which are partly removed in the carbon gas, although experience indicates their presence in the finished article. Foreign matter, infinitesimal in quantity, gives rise to equal minute explosions, the effect of which is to coat the interior of the lamp bulb with the film already noted. Oxygen gas is to some extent retained after the carbonization, but it is supposed to be entirely removed and absorbed during the flashing.

Effect of Flashing

The flashing process is one of the most important steps in the manufacture of an efficient lamp. Siemens & Halske, of Germany, made an exhaustive series of tests for the purpose of determining the relative merits of the treated and untreated carbon filaments with respect to the hydro-carbon or flashing process. Their results are tabulated as follows:

LAMPS WITH UNTREATED CARBONS

Burning Hours	Volts	Current in Amperes	Candle-power (C. P.)	C. P. per H. P.	Watts per C. P.
0	100	0.687	24.25	259	2.8
100	100	0.666	15.7	173	4.2
200	100	0.666	15.3	169	5.0
300	100	0.664	15.2	167	4.4
400	100	0.653	14.7	165	4.5
500	100	0.640	13.7	157	4.7
600	100	0.634	13.3	154	4.8
700	100	0.630	13.1	153	4.9
800	100	0.620	12.5	148	5.0

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The results with treated carbons are doubly interesting when the column indicating the watts per candle-power are examined, particularly in connection with the number of hours burning.

LAMPS WITH TREATED CARBONS

Burning Hours	Volts	Current in Amperes	Candle-power (C. P.)	C. P. per H. P.	Watts per C. P.
0	100	0.552	25.0	333	2.2
100	100	0.550	22.5	300	2.4
200	100	0.550	22.0	290	2.5
300	100	0.548	21.0	282	2.6
400	100	0.547	20.0	270	2.7
500	100	0.545	18.6	251	2.9
600	100	0.545	17.1	231	3.2
700	100	0.540	16.0	218	3.4
800	100	0.532	15.3	210	3.4

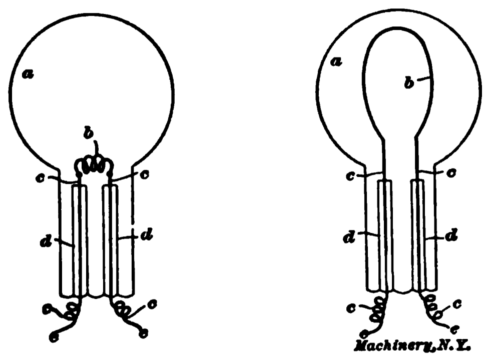

Fig. 21. Comparison between Crookes' Radiometer and the Incandescent Lamp

Summing up the results, the following data is of interest with respect to these figures:

	Treated Carbons	Untreated Carbons
Decrease in efficiency (per cent)	36.9	57.10
Decrease in illumination (per cent)	38.8	51.50
Average illumination, candle-power per lamp	19.67	14.91
Average output in candle-power, per H. P.	264.1	167.70
Increase in resistance in per cent	3.8	10.80

The increase of over 30 per cent in light due to the hydro-carbon treatment establishes the immense value of this process in the commercial manufacture and use of lamps.

Making the Lamp

The filaments, after flashing, are ready to be enclosed in a glass bulb. This arrangement is a rather old discovery. Sir William Crookes invented a "radiometer" consisting of a glass bulb with leading-in wires, an account of which was published in the Philosophical Transactions of the Royal Society of London about the time that lamp-making only existed as an experiment. In this piece of physical apparatus leading-in wires of platinum were employed and a vacuum used

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to develop the maximum effect with the illuminating element. The incandescent lamp differs only from this in the use of a carbon horseshoe or high-resistance arch joining the platinum terminals, as shown in Fig. 21. In both figures in this illustration, *a* is the exhausted glass chamber, *b* is the illuminant or incandescent conductor, *c* shows the leading-in wires of platinum, to which the ends of the illuminant are attached, and which are hermetically sealed by fusion into glass tubes *d*. The main conducting wires are attached at *e*.

The glass bulbs for the lamps are blown from glass tubing about ¾ inch in diameter with walls ⅛ inch thick. Afterwards a tube is formed on the lower end of the lamp about 3/16 inch in diameter and 3 inches long, this tube being used for attaching the bulb to the

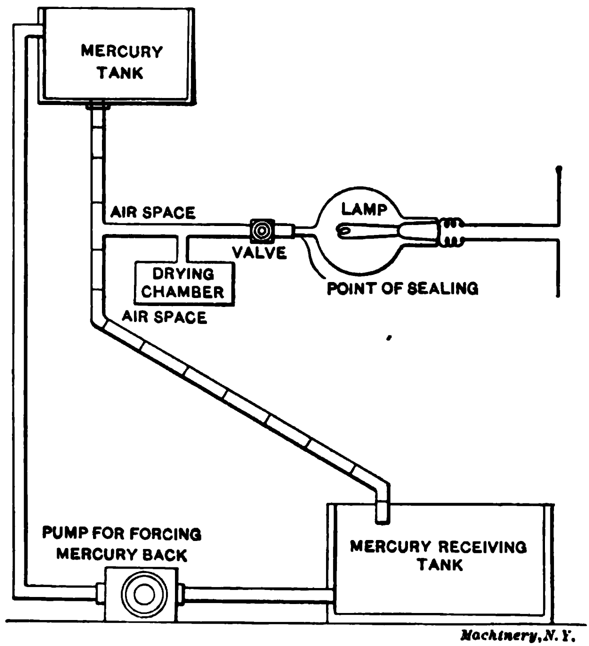

Fig. 22. Mercury Column Vacuum Pump

vacuum pump. The filament is then inserted into the lamp and the upper end closed around the glass tube in which the leading-in wires are held. After this the bulbs are connected to the vacuum pumps for exhausting the air.

The Vacuum Process

Pumps for the purpose of creating a good vacuum have reached a comparatively high stage of development. They are constructed on the general principle of the Torrecellian method of producing exhaustion by means of mercury in a glass tube. If a tube sealed at one end and about 40 inches in length is filled with mercury, and then its open end is carefully inserted in a deep vessel containing the metal, the

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mercury will fall away from the upper sealed end to some extent. In this empty space is found what was originally called a Torrecellian vacuum, a vacuum of a very high degree of exhaustion.

The pumps originally employed in exhausting the lamps were of a type in which a falling column of mercury produced a vacuum in the lamp by dropping down a tube to which the lamp was attached. The junction was effected on the side of the tube between the lamp and exhaust pump. Globules or spaces form between the various sections of the mercury column. A systematic process of rarefaction goes on until the exhaustion reaches a point where the pressure is but a small fraction of an atmosphere. A diagrammatic sketch of this pump is shown in Fig. 22. This type of pump, however, is used only for laboratory purposes. For regular lamp manufacture, special mechanical rotary air pumps are now employed.

During the process of exhaustion the lamp has a weak current sent through it, only sufficient to heat the carbon and the surrounding air. As the rarefaction increases the current is increased, until at the end of the process the lamp burns with full candle-power.

The absence of air around the filament means less immediate radiation from the incandescent mass to the outside air. The value of this is found in the lower current value required to heat the filament to incandescence. The lower the current value the higher the efficiency, other things being equal. By means of a vacuum a degree of commercial economy is obtained which lifts the incandescent lamp, light for light, to a much higher plane than gas. The relative efficiencies may be noted in the following general manner as about 10 per cent for the arc light, 3 per cent for the incandescent, and 1 or 1.5 per cent for gas. Using a neutral gas in the bulb would mean a subtraction of heat from the filament to the outside air. This is not an efficient method, and for that reason has been practically discontinued.

Since the degree of exhaustion must be high, the bulb should be heated during the process of obtaining the vacuum, so as to drive off any gas which may cling to the glass. Immediately after the pumping process is completed, and before the lamp is finally sealed, previously introduced chemicals consisting of mercury sulphide or other suitable oxygen-absorbing mercury salts are heated in the small tube by means of which the lamp is connected with the air pump, and this serves to take up practically all of the remaining oxygen.

The prevalence of moisture is one of the difficulties in obtaining a complete vacuum. In order to make this difficulty as negligible a feature as possible, the moisture is largely removed by means of a small drying tank attached to the pump. This little vessel contains a vapor-absorbing mixture, such as sulphuric or phosphoric acid, called the drying solution. Lamps using no vacuum have come into the lighting field, but in this case the material giving incandescence is an inoxidizable substance.

After the vacuum process is completed, the glass tip, connecting it by an orifice to the exhaust tube, is melted and sealed permanently. In actual practice a long string of lamps are treated simultaneously

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in this manner, the exhaustion and final sealing forming part of a rapid process

After the lamps have been exhausted, they are tested and then the metal cap or top is finally attached. Plaster of paris is used between the cap and the glass bulb in order to give firmness and solidity to the joint, proper connections being made with the leading-in wires. The lamp is now complete, and is again tested to see that the contacts are properly made, after which they are packed in baskets and kept at a temperature of 90 degrees F. for four or five days, so that the plaster of paris may thoroughly harden, after which they are again tested to see that the caps have remained straight during the drying of the plaster. When the globes are to be frosted, this is done by holding them in a sand-blast.

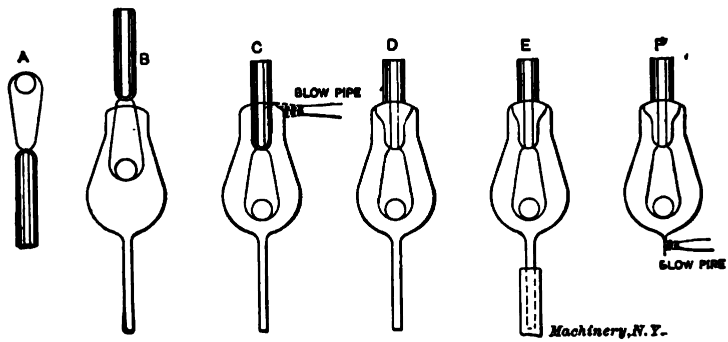

Fig. 23. Successive Stages in Lamp Manufacture

In Fig. 23 the successive processes in lamp manufacture are indicated. At *A* is shown the filament as attached to the platinum leading-in wires inserted in a small glass tube. It should be understood that platinum is used only for the short distance where the wire must pass through the glass wall, the platinum wires being not more than 1/8 inch long. The remainder of the leading-in wire is of copper. At *B* the glass bulb is shown with the filament ready to be inserted, and at *C* the filament is shown in place, the blowpipe being applied for sealing up the bulb at the top. At *D* the bulb is indicated as sealed. At *E* the vacuum pump is connected, and at *F* the blowpipe is finally applied at the lower end of the lamp, and the lamp sealed. Of course, this illustration is only diagrammatical and merely serves the purpose of indicating the various operations.

Metallic Filament Lamps

Metallic filament lamps have been used successfully only during the last few years. The first successful metallic filament lamp was the tantalum lamp, but the one now most commonly used is the tungsten lamp.

The chief advantages of the tungsten lamp are that tungsten can be heated to a very high temperature without fusing, and hence gives out a very brilliant light, and that the lamp consumes far less current

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per candle-power than the ordinary carbon lamp. Edison's first incandescent lamp, using a bamboo filament, consumed from 4 to 4½ watts per candle-power. The present day carbon filament lamp consumes from 3 to 3½ watts per candle-power. In the metallic filament lamps these figures are considerably reduced, so that the tantalum lamp, for example, consumes only from 2 to 2½ watts, and the tungsten lamp from 1½ to 2 watts per candle-power. The disadvantages of the tungsten lamp are its higher cost and the fragility of the filament when no current passes through it. Owing to the low electrical resistance of tungsten, it is necessary to employ a very long filament as compared with that in carbon lamps, the filament for a 110-volt lamp, for example, being 30 inches long. This filament is mounted in the lamp on supports as shown in Fig. 24. Although tungsten itself occurs abundantly in nature, and is a comparatively cheap metal, the cost of producing the long filament is the cause of the higher cost of the lamp; the fragility is due to the fragile nature of the fine tungsten thread and the unsatisfactory method used for mounting it in the lamp, which is made necessary by the fact that the filament cannot, as yet, be procured in sufficiently long single lengths for a whole lamp.

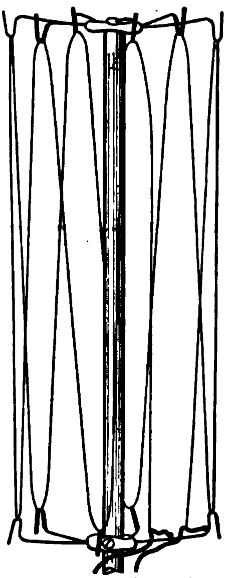

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Fig. 24. Tungsten Lamp

The tungsten filament is, mechanically, quite similar to glass. A slender rod or thread of glass has great tensile strength and it can be bent; the smaller the diameter the more can it be bent without breaking. But it is fragile, and a slight blow shatters it. When it is warm it becomes quite soft. This description applies equally to the tungsten filament. Now, either a glass or a tungsten rod or filament, if rigidly held at one point is much more apt to break than if loosely supported. And yet the fragile tungsten filament is held rigidly at its ends. In the ordinary lamp the total filament consists of four or five hairpin shaped parts, each rigidly fastened to stiff wires at its ends, making a total of eight or ten points of rigid support. The support is made absolutely rigid, usually by electrically welding or fusing the supporting wire around the tiny filament. The result is that one of the best known features of the lamp is its fragility, and the mechanical break almost invariably occurs near the fused support.

The reason for this unfortunate construction is that tungsten filaments can only be made in short lengths in hairpin shape. It has not been practicable by usual methods to make and mount single filaments having a length of 30 inches, more or less, which is necessary for a 110-volt lamp. Consequently it has been common practice to connect in series a number of individual short filaments by fusing their ends

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to stiff supporting wires; hence, the disadvantage of rigidly supported, delicate and fragile filaments results from the necessity of using many individual filaments, adapted in length to the size of the lamp bulb. The ideal way to overcome these difficulties would be to employ a single filament and to mount it without rigidly fastening it to its supports. This requires three things. First, a single or continuous filament; second, a loose winding back and forth around supports at numerous points, giving a final form appropriate to the ordinary lamp bulb; and, third, a suitable electrical contact with the leading-in wires, eliminating the fatal rigidity.

To sum up, the tungsten lamp has very quickly established its claim as to high efficiency, excellent light and general acceptability. On the other hand, a feature of the lamp which is firmly fixed in the minds of all who have had to do with it is its fragility. Its liability to accidental breakage in handling and in service is its great handicap. Whenever, therefore, an improvement is made in the materials or construction of the lamp, which will materially reduce its fragility, an important commercial advance will have been made. The life of the lamp, if the filaments remain unbroken, is about 1,000 hours.

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CHAPTER IV

SPECIAL TYPES OF LAMPS

Besides the ordinary arc lamps and incandescent filament lamps commonly used, and described in detail in the previous chapters, a number of different types of electric lamps and methods for electrical illumination have appeared from time to time, some of which have proved very successful. Among these must especially be mentioned the Nernst lamp, and the mercury vapor lamp, also known as the Cooper Hewitt light.

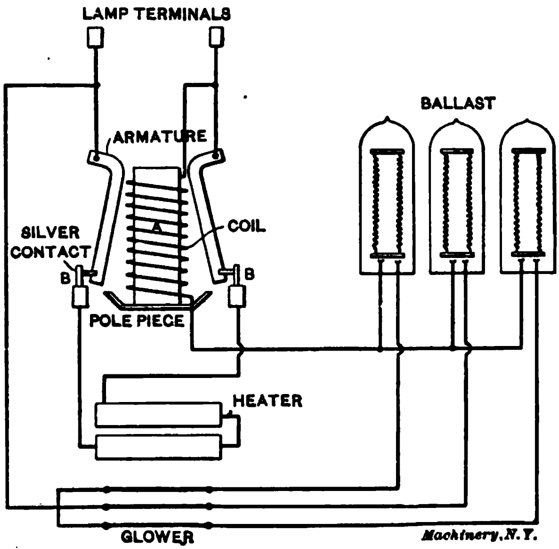

Fig. 25. Wiring Diagram of Nernst Lamp

The Nernst Lamp

The Nernst lamp, also known as the glower lamp, employs for its incandescent material a fine rod made of rare oxides, the exact composition of which appears to be a "trade secret." The oxide is originally made in the form of a paste, and then forced through a die in order to give it the required shape. The *glower* thus formed is then dried or "roasted," cut to the desired length for the lamps, and provided with platinum terminals to make contact with the circuit. The rare oxide rod or glower is non-conducting when cold, and must, in consequence, be heated before it can conduct the current and produce light. Therefore, a heater is required for the lamp, which will bring the temperature of the glower up to a point where it will become a conductor. The

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heater works automatically when the light is turned on, it being connected across the circuit, but it is also necessary to cut it out automatically as soon as the glower has reached the required temperature, as it would otherwise quickly deteriorate. The automatic cut-out is accomplished by means of an electromagnet so connected that current flows through it as soon as the glower has become a conductor. This electromagnet operates a contact cutting out the heater.

The heaters are made in two forms. One kind of heater consists of a platinum wire wound around a porcelain tube and covered with porcelain to prevent too rapid deterioration. Such a heater is shown in the diagrammatical wiring diagram of a Nernst lamp in Fig. 25. As shown, it is mounted just above the glower, and is known as a heater tube. The second kind of heater is of the type shown in Fig. 26. It is known as a spiral heater, and consists of platinum wire wound around a porcelain rod, and covered with porcelain, the whole being then bent to a helical form which surround the glower.

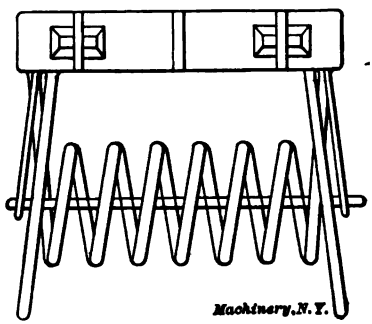

Fig. 26. Spiral Heater for Nernst Lamp, consisting of Platinum Wire wound around a Porcelain Rod

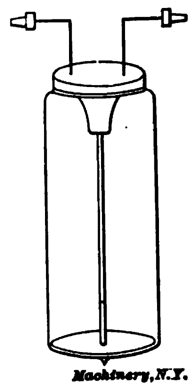

Fig. 27. Ballast Resistance of Nernst Lamp

When the current is turned on, the glower is heated, and then the heater cut out as already mentioned. When the current is turned off, the contacts for the heater assume their normal position, closing the circuit, so as to be ready for action when the current is again turned on. The closing of the heater circuit when the current is turned off is accomplished by means of gravity, so that it is necessary that lamps of this description should be mounted in a specific position.

The fact that the resistance of the glower decreases with an increasing temperature, introduces a peculiar condition in the construction of this class of lamps. If the lamp were used on a constant-potential circuit, without any means of regulation, the temperature of the glower would continue to increase (due to the greater amount of current flowing through it, on account of its increasing conductivity) until the glower would be entirely destroyed. In order to check this action, a resistance in the form of an iron wire, is connected in series with the glower. This resistance is called a ballast or a ballast resistance.

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As the resistance of iron increases with an increasing temperature, it is possible to so adjust the resistance of the entire circuit that a balanced condition is obtained when the current reaches a given strength. In order to prevent oxidation of the iron wire, it is mounted in a glass tube or bulb containing hydrogen, in a manner as shown in Fig. 27, and as indicated in the wiring diagrams Figs. 25 and 28. The reason why hydrogen has been selected in preference to other gases which might have been used as well for their non-oxidizing properties, is that it conducts the heat from the iron wire better than other gases.

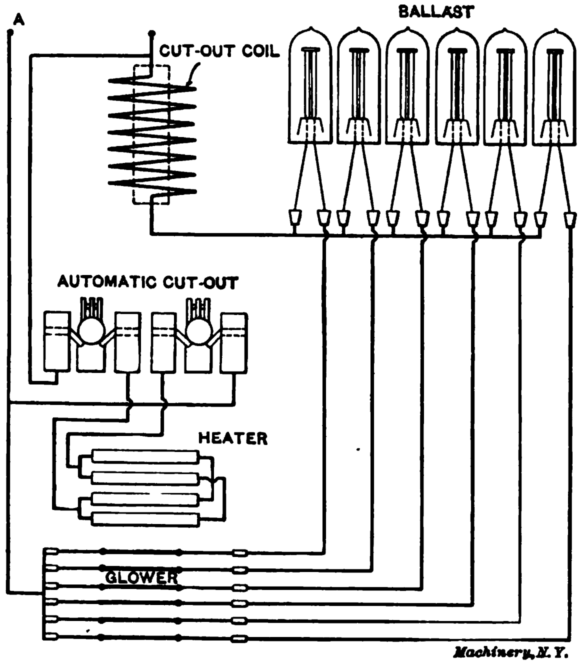

Fig. 28. Wiring Diagram of a Six Glower Nernst Lamp

To sum up, the Nernst or glower lamp consists of four main constituent parts, as follows:

1. The rare oxide rod or glower which gives the light at a high temperature.

2. The heater for raising the temperature of the glower when the current is first turned on.

3. The automatic cut-out for the heater after it has done its work.

4. The iron wire ballast contained in a tube of gas which regulates the amount of current.

The parts enumerated are mounted together, smaller lamps having but one glower, and being made to fit a standard incandescent lamp socket, while larger lamps are made with as many as six glowers, and are supported the same as ordinary arc lamps.

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The standard makes of Nernst lamps possess a glower which takes about 220 volts, is 1 inch in length and about 1/40 of an inch in diameter. The temperature at which the light is produced varies from 1,200 degrees F. to 1,400 degrees F., depending upon the current. A fair average is 1,300 degrees F., at which temperature the normal light appears.

The candle-power tests give results as follows: A two-glower, 220-volt lamp gives about 70 candle-power with a watt consumption of about 170, or about 2.5 watts per candle-power. The light given out during the life of the lamp is very white and agreeable to the eyes when passed through sand-blasted globes.

The glower lamp needs no vacuum, because the filament cannot be consumed in the air. If enclosed in a vacuum, the absence of air produces a higher temperature and a lower resistance; in consequence, more ballast is required to cut down the current, so the efficiency is not advanced to any remarkable extent by this method.

The general arrangement of the wiring for Nernst lamps is indicated in Fig. 25, for a three-glower lamp, and in Fig. 28, for a six-glower lamp. In the former illustration, the automatic device for cutting out the heater has been shown in detail. As soon as current begins to flow through the glowers, the electro-magnet *A* is also energized, and the silver contacts at *B* are opened, thus preventing current from flowing through the heater coils. In Fig. 28, the current enters at lamp terminal *A* and then passes through the contact of the automatic cut-out to the heater coils. When the glowers begin to conduct, current will pass through the cut-out coil, and this will open the contacts of the automatic cut-out, thus rendering the heater inoperative. On some of the newer types of lamps, the spiral heater is used in preference to the heater tubes, and both glower and heater are so mounted that they can be very quickly replaced. The life of the glower is about 700 hours. Nernst lamps are used exclusively on alternating current circuits.

The Mercury Vapor Lamp

The mercury vapor lamp, invented by Cooper Hewitt, has gained considerable ground in a few years. Its chief advantage is that it consumes a very small amount of current per candle-power, the current consumption being only about 0.55 watt per candle-power. The objection to this lamp is that it gives out a light devoid of red light-rays, and, therefore, apparently, changes the color of objects illuminated by it. This absence of red rays makes the light very agreeable to the eyes, however, although it limits the application of the lamp to such places where its color is of no importance.

In this lamp the source of light consists of mercury vapor which is rendered incandescent by the passage of an electric current through a long glass tube from which the air is exhausted, and in which the vapor is contained. To one end of the glass tube is attached an electrode either of iron or mercury, while the other electrode is always of mercury.

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When the lamp is to be started, mercury vapor may be formed in one of two ways. One method is by means of a high-tension spark which jumps between the electrodes, and thus forms the required conducting vapor. To obtain the spark, it is necessary to provide a powerful inductance coil and a quick-break switch. The other method used for starting the lamp is to tilt the tube until a stream of mercury is formed from electrode to electrode; the tube is then permitted to resume its

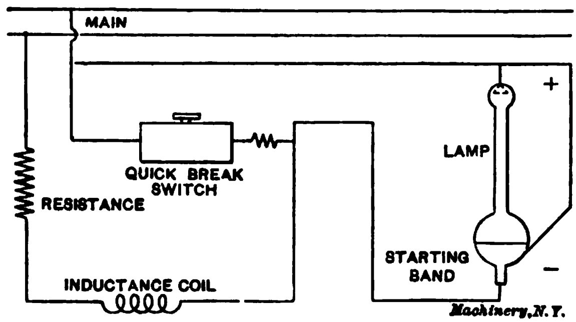

Fig. 29. Mercury Vapor Lamp started by High-tension Spark

original position, enough vapor having been formed to provide a conducting bridge between the electrodes. The mercury vapor lamp is especially adapted to operate on direct-current circuit, but considerable advance has been made in developing an alternating current lamp as well.

In Fig. 29 is shown a lamp circuit where the lamp is started by a high-tension spark. Fig. 30 shows the wiring diagram for two lamps

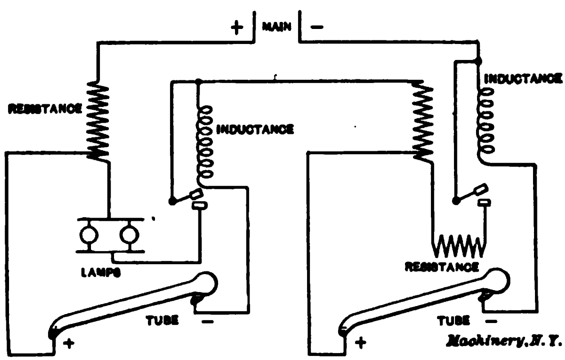

Fig. 30. Wiring Diagram for Lamp started by the Tipping Method

in series and arranged for being started by the "tipping" method.

Some general data relating to mercury lamps may be of interest. The length of the glass tube varies from 43 to 49 inches, according to the voltage. The diameter is 1 inch. The strength of the current is from 3 to 3.5 amperes, which with a voltage of 110 volts gives a candle-power of about 650. The life of the lamp is from about 1,000 to 1,600 hours.

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The candle-power being unusually high for a small amount of current would make this light universal in application if red rays were present. Their absence, however, limits its use to docks, large lofts, factories and places where the color problem plays no important part. The suggestion once advanced that the tube be made of red glass to supply the missing rays would mean darkness instead of light. As there are no red rays in the light, and as none but red rays can pass through red glass, it is obvious that no light would penetrate the walls of the tube. The only remedy would be to provide a means of developing red rays in the tube itself by the introduction of another element or a modification of the method.

The Moore Tube Light

If a gas is contained at a high vacuum in a glass tube, and the tube is provided with electrodes and a high-tension alternating current forced through the gas, the latter will glow with a soft luminescence. The color of the light produced is governed by the gas contained in the tube. Carbon dioxide produces a white, diffused light, very similar to daylight, while nitrogen produces an orange light.

The Moore tube light is based upon the principles outlined above. It consists of a very long glass tube containing the gas at the required degree of vacuum. A transformer must be employed to obtain the necessary high voltage of the alternating current sent through the tube. As the gas used gradually deposits on the glass wall of the tube, and as it is necessary that a certain degree of vacuum be maintained, an automatic valve is provided for supplying the required amount of gas, whenever the vacuum becomes too great. The reason for the very long glass tubes used is that the intensity of the light is only about 0.65 candle-power per square inch of tube surface. The efficiency of the light tubes, however, is stated to be equal to that of tungsten filament incandescent lamps.

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NUMBER 77

PRINCIPLES AND APPLICATIONS OF ELECTRICITY

PART V

TELEGRAPH AND TELEPHONE

CONTENTS

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CHAPTER I

THE TELEGRAPH

The first attempts to transmit messages by the aid of the electric current were made as early as in the eighteenth century. According to the authorities on the history of telegraphy, Le Sage of Geneva produced a simple system of telegraphy as far back as in 1774. His methods, however, proved impractical, except for demonstration purposes. Other early inventors in the field of telegraphy were Lomond and Cavallo, whose inventions date back to 1787 and 1795, respectively, Ronalds, Soemmering, Ampere, Henry, Schilling, Weber, Cooke and Wheatstone all produced different apparatus, with more or less success, during the early part of the last century. The first permanently practical success, however, was attained by Morse in 1837. Since the time of Morse a number of improvements have been made, and various systems known as the diplex, duplex, quadruplex and multiplex have been developed. The names connected with the invention and development of these systems are Gintl, Stearns, Stark, Bosscha, Heaviside, Edison and Delany. In addition to these inventors should be mentioned the names of Hughes, Cowper and Elisha Gray, and especially Lord Kelvin, to whom a great deal of the success of cable telegraphy is due. Among all the various systems for transmitting messages by wire by means of the electric current, the only one, however, which calls for an extended description in an elementary treatise, is the Morse system. Wireless telegraphy will be treated in detail in the following chapter.

Two successful methods, known as the open-circuit and the closed-circuit systems are at the present time in use for telegraphy with wires. The closed-circuit system is used almost entirely in the United States, while the open-circuit system is used largely in Europe. The difference between the two systems, in principle, consists simply in the fact that when the apparatus is not in use for sending messages, a switch is connected, or "closed," in the closed-circuit system so that the current flows continually through the line, while in the open-circuit system no current is consumed from the batteries except when signals or messages are actually being transmitted. This is the chief advantage of the open-circuit system. The closed-circuit system, however, has other advantages which off-set this. The two systems call for a different arrangement of batteries.

A diagrammatical sketch of the arrangement of a closed-circuit system of telegraphy is shown in Fig. 1. In its simplest form this system contains three principal parts, key, sounder and battery, connected in series in the circuit. When a message is to be sent, the switch, already mentioned, is disconnected or "opened," thus opening the circuit. The message or signal is then sent by means of a telegraph key, which, when operated, closes the circuit. When the circuit is thus closed, an

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instrument receiving the message or signal, and consisting primarily of an electromagnet with spring-balanced armature, is thrown into operation, this instrument, giving a loud click, being called a sounder. A battery or series of batteries is used for furnishing the current for

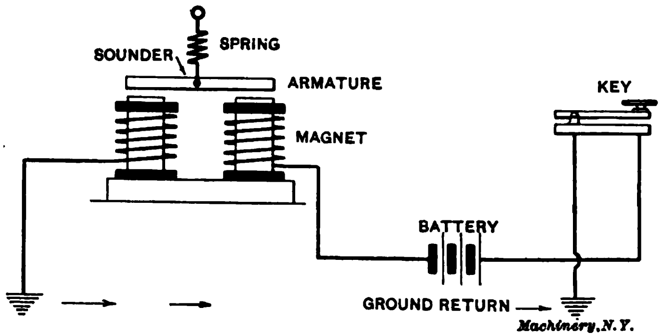

Fig. 1. Diagrammatical View of the Arrangement of a Closed Circuit System of Telegraphy

operating the system. Only one wire is used, the system being connected to the ground at each end, and the earth being used for the return.

The Sounder

The sounder consists of a pair of vertically mounted electromagnets which attract an armature against the tension of a spring. The open-

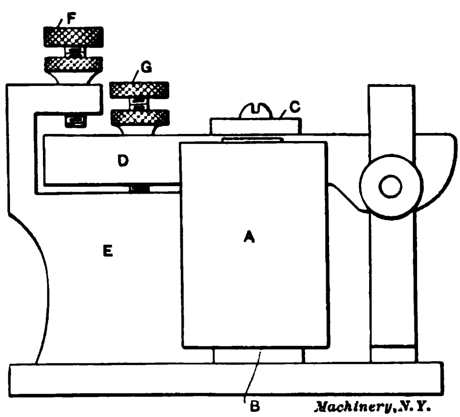

Fig. 2. Elements of the Sounder

ing or closing of the circuit by means of the telegraph key either releases or attracts this armature. A simple construction of the sounder is shown in Fig. 2. At *A* is shown one of the electromagnets, the other being directly behind it. The electromagnet is made up of two cores and a yoke *B*. At *C* is shown an armature of soft iron, this armature being attached to a lever *D* made of a non-magnetic material. This lever is controlled by a spring not shown in the illustration, so

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that the armature is held away from the electromagnet, whenever a current does not pass through the coils around the latter. When, however, a current passes through the coils of the electromagnet, the cores are magnetized, and the armature is attracted or held by the magnetic action. The armature, however, does not touch the end of the cores, because the instrument is so adjusted that immediately before the armature would touch the end of the core, a stop-screw *G* through the lever *D* strikes the bracket *E* and a click is heard. When the current ceases to flow, that is, when the key at the sending end is released so as to open the circuit, the magnetic force of the cores of the electromagnet ceases to exist, and the armature is thrown upwards by means of the spring, as already mentioned. The lever then strikes a stop-screw *F* and another click is heard. It is this succession of clicks that make an intelligent transmission of messages possible. When the time during which the current flows is very short the interval of time between the two clicks will be correspondingly short, and the signal in that case is a "dot." If the interval between the two clicks is longer the signal is called a "dash." The telegraphic code ordinarily called the Morse code is made up of various combinations of dots and dashes, each combination signifying a certain letter or figure, as shown below:

A	. —	J	— . — .	S	. . .	1	. — — .
B	— . . .	K	— . —	T	—	2	. . — . .
C	. . .	L	———	U	. . —	3	. . . — .
D	— . .	M	— —	V	. . . —	4	. . . . —
E	.	N	— .	W	. — —	5	— — —
F	. — .	O	. .	X	. — . .	6	. . . . . .
G	— — .	P	. . . . .	Y	. . . .	7	— — . .
H	. . . .	Q	. . — .	Z	. . . .	8	— . . . .
I	. .	R	. . .	0	———	9	— . . —

The system as outlined above is called the American Morse code. There is also an International code which differs to some extent from the American Morse code. Both, however, are founded on exactly the same principle of combination of dots and dashes. When a message is sent an interval is introduced between each letter and a longer interval between each word. In the original system the instrument was combined with a writing apparatus which recorded the dots and dashes, and entire reliance was not placed on the ear of the operator in taking the message directly from the sounder. This recording system is still in use to a considerable extent in Europe, but hardly used at all in America. It has been found that the ear is more reliable than the eye, that a simple sounder, therefore, is preferable to a recording mechanism.

The two systems used for recording the messages are called the embosser and the ink-writer systems. In the embosser system a sharp pointer fastened to the armature lever cuts dots or dashes in a strip of paper moved past it by means of an automatic apparatus operated by clockwork. In the ink-writer system, the dots and dashes are recorded on a moving strip of paper by an inked wheel or pointer.

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The key or sending apparatus of the Morse telegraphic system is shown in Fig. 3. In its simplest form it consists of a lever *A* pivoted a certain distance past its center, at *B*. The hand or fingers of the operator rest at *C*. At *E* is a binding screw, securing the instrument to its base; this screw also acts as an electrical connection to the main body of the key and lever *A*. At binding screw *F* is a connection to platinum tip *G*, which is insulated from the rest of the apparatus. Another platinum tip *H* is placed on lever *A*, which makes contact with

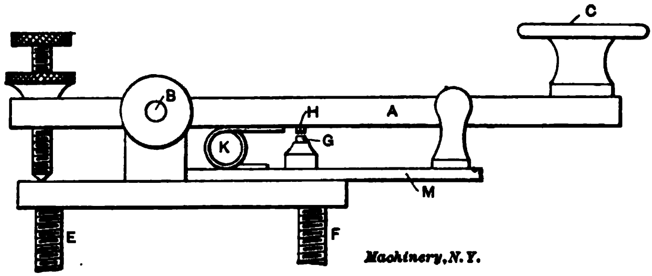

Fig. 3. The Key or Sending Apparatus

G when the lever is pressed down, thus completing the circuit through the key. When the key is not used, the lever is kept in a proper position by a spring *K*. When the instrument is not in use, switch *M* is used for closing the circuit. This completes the simple arrangement of the key or sending apparatus.

The Relay

Although the chief constituents of a simple telegraph system consist of a sounder, battery, key and line, another important adjunct in the shape of a relay becomes necessary when the telegraph system comprises a long line having many instruments in series. In this case the

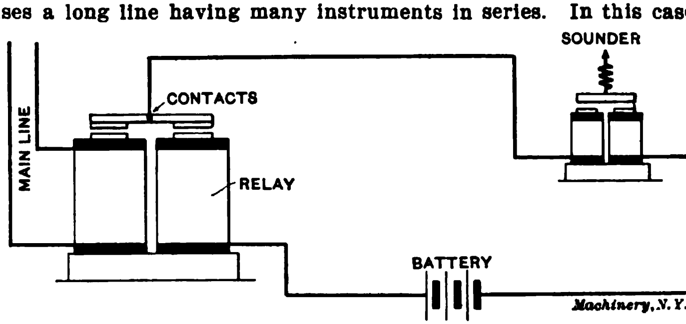

Fig. 4. Diagrammatical View showing Action of Relay

main current is not strong enough to operate the sounder at the receiving station directly, and a device called a relay is then resorted to. This instrument is employed for the purpose of receiving the incoming signal and for throwing into action a new set of local batteries which supply the current for reproducing the signal with greater emphasis. In other words, when the armature of the magnet constituting the re-

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lay is attracted by the magnet, it closes a new local circuit in which is a sounder, as indicated in the diagrammatical view in Fig. 4.

When a receiving apparatus is provided with a relay the instrument is usually provided with a horizontal electromagnet having a large number of turns in its coils, and an armature arranged practically the same as in the ordinary simple sounder. The coils in the electromagnet mentioned are in series with the main line current. The armature of this electromagnet is very carefully balanced, so that a very small electromotive force will attract it. In this way a very small current will be sufficient for producing a contact through which can flow a local circuit supplied with current from a sufficient number of batteries and operating an ordinary Morse sounder.

From this it will be understood that the ordinary telegraph station contains a connection to the main line and in addition to this it has its own local circuit by means of which it is able, so to speak, to reinforce the current of the main line so as to deliver the messages in an intelligent form. The reason why the main line current cannot be used directly is due to the conditions of the line. Leakage occurs to some extent so that the current becomes too weak to produce an effective signal. The leakage may be due either to the length of the line or to defects in the insulation.

The sounder is provided with two binding posts or electrical contacts which connect one directly with the battery, and one with the battery *via* the relay. The relay possesses four binding posts, two of which connect with the incoming line and two of which complete the circuit of the sounder and its battery. The sounder, relay and key are generally mounted on one board for convenience. The relay, for its operation, takes only about one-tenth of the current that would be required for the sounder. In fact, the relay current is so small that it cannot be measured by the ordinary electrical measuring instruments. Its strength is estimated in thousandths of an ampere. The relay usually requires 0.010 ampere (10 milliamperes) if well adjusted, and sometimes the current required may be even less than this.

Adjustments

The adjustment of the armature of the relay, and of the sounder as well, is of great importance. If the armature is properly adjusted, it will require a smaller volume of current to operate than otherwise. It is evident that the closer the armature lies to the iron cores of the magnet, without actually touching them, the stronger will be the magnetic force by which it is attracted, and as regards the sounder, the louder will be the click that results from the closing of the circuit. The best way to adjust the sounder armature is to first insert a thin piece of paper between the armature and the iron pole-piece of the electromagnet, and then let the lever down until it touches and holds the paper while the key is closed. The adjusting screw is then manipulated until the paper can be just pulled out, the adjustment then being made permanent by means of the locknut shown in the illustration, Fig. 2. The other screw is then adjusted so as to give the proper dis-

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tance or play for the lever. The spring in the sounder, not shown in Fig. 2, is also provided with an adjusting screw regulating its tension, so that a certain relation between the strength of the up and down stroke of the lever can be produced in order to make the signals received easily audible or "read."

Referring to Fig. 1 it will be seen that the sending and receiving apparatus are connected only by one line of wire, the instruments being connected to the ground at each end of the line, as already mentioned, and the return being through the ground. By this means it is possible to transmit messages without having a return wire, a single line

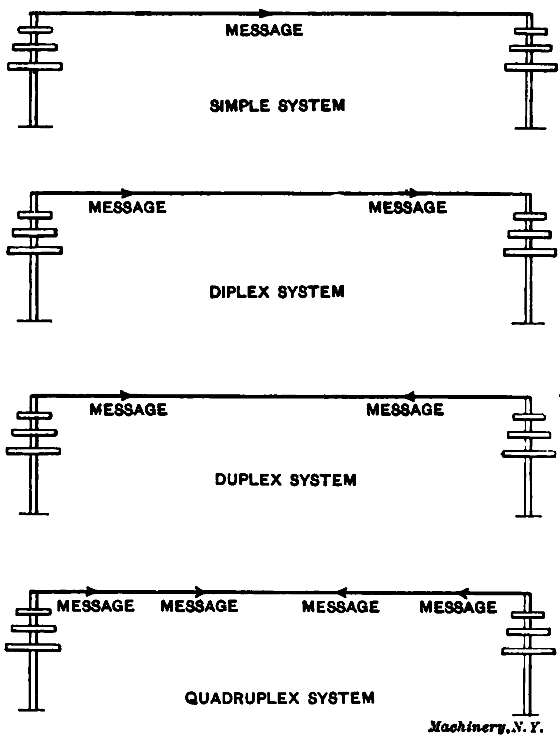

Fig. 5. Graphical Illustrations of Principles of Various Systems of Telegraphy

only being necessary. The batteries may all be placed at one end of the circuit if preferred, or may be divided and placed half at each end. The arrangement of the batteries is immaterial as far as the principle of action is concerned. The batteries for operating the sounder in the local circuit connected by the relay are, of course, placed in the local stations.

Number of Messages Sent Over One Wire

The number of messages that may be sent over one wire at the same time depends upon the character of the apparatus at the ends of the

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line. With regard to the number of messages that may thus be sent, a number of systems have been developed, known as the simple, the diplex, the duplex, the quadruplex, and the multiplex systems.

The simple system merely permits the transmitting of a signal, one at a time, over the wire.

A diplex system is one by means of which two distinct signals may be sent at the same time *from one end* of the wire without confliction and be received at the other end without trouble. These signals or messages both travel in the same direction.

A duplex system permits a message to be sent from each end of the line at the same instant without confusion. It differs from the diplex

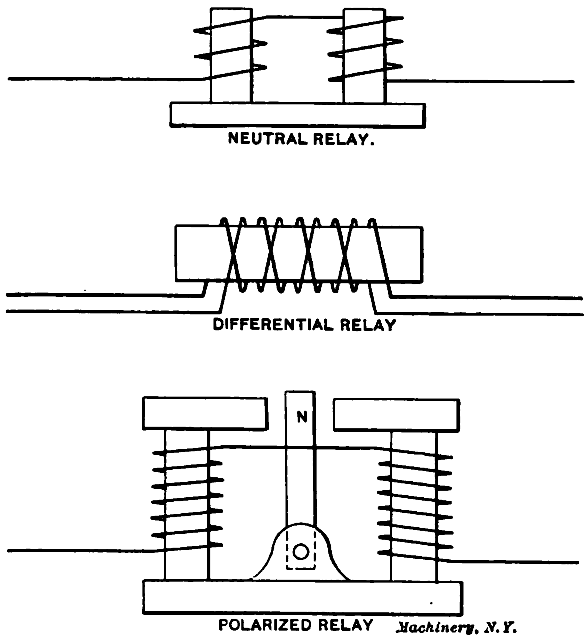

Fig. 6. Windings of Different Types of Relays

as regards the direction of the messages. The diplex sends both one way, the duplex both in opposite directions at the same time.

A quadruplex system is one in which two messages may be sent from each end of the line at the same instant, making four in all, two moving in one direction, and two in the opposite direction. This system might be called either a double diplex, a double duplex, or a combination of a diplex and duplex system. The latter idea is carried out in practice, in that devices are used by which the line is both "diplexed" and "duplexed" for the purpose of conveying four messages at one time. The principle of the various systems is graphically illustrated in Fig. 5.

This principle can be carried out beyond the point of the quadruplex system, in fact, to such an extent that eight messages may be trans-

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mitted simultaneously, in which case, octuplex, or, simply, multiplex, is the name given to the system; but a development of this kind would naturally call for the use of a more and more complicated system of devices. Patrick B. Delany invented a system in which complications of this kind are avoided. His system is known as the Delany synchronous system of multiple telegraphy.

The Diplex System

The practical principle employed in telegraphy for the purpose of obtaining different sets of signals over the same line is that of using certain keys to operate certain relays—one key, for instance, sending over the line a powerful current which actuates one relay, and another key controlling the direction of the current and, therefore, operating another type of relay. In other words, the keys are selective with respect to the relays. It is necessary to examine the types of relays before the subject can be properly comprehended.

The relays may be classified, according to the character of the current which will actuate them, as neutral relays, differential relays, and

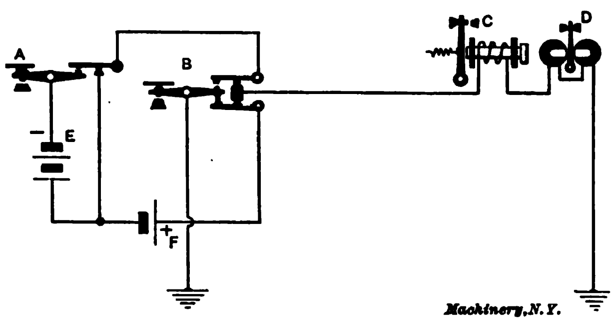

Fig. 7. Arrangement of Keys for Diplex System of Telegraphy

polarized relays. The principles of winding these various relays are diagrammatically illustrated in Fig. 6.

The neutral relay is, as its name implies, a relay operated by an ordinary current irrespective of its direction. The current must be of sufficient strength to cause emphatic movement of the relay armature.

The differential relay is an electromagnet possessing two distinct windings, each wound opposite to the other and each of exactly the same number of turns and resistance. The equivalence of the turns makes the magnetic effects alike; therefore, the passage through the coils of two equal currents would leave the relay inoperative.

The polarized relay is supplied with a permanently magnetized armature. One pole of this armature lies between the two poles of an electromagnet. When this magnetized armature moves decidedly in one direction or the other it is because the current in the electromagnet is flowing in a certain direction. The armature is polarized for the purpose of making the relay sensitive to changes in the direction of current.

In Fig. 7 two keys are shown. The first, *A*, as indicated, will have

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the effect of sending into the line the current of three cells of battery. The key, it should be noted, has no control over the direction of the current. When it is moved down it operates the first relay *C*, a neutral relay of the type previously described. The current passing through the second polarized relay *D* is ineffective because it lacks the direction required to throw the armature on the particular side which closes the contacts governing the local circuit and its sounder.

The second key *B* is a reversing key, or pole-changing transmitter. Its only function is that of sending a relatively weak current into the line, which is either positive or negative, depending upon the position of the key. This weak current cannot affect the neutral relay which remains unresponsive to the currents passing through it unless sent by the first key *A*. The batteries *E* and *F* will act in combination when key *A* is pressed, giving, therefore, a high electromotive force. When the key *B* is pressed to operate the relay *D* only one cell of battery *F* is in action. Hence, key *B* sends a weaker current into the line, but varies its polarity with reference to the line, and therefore actuates the more delicately adjusted relay previously mentioned. Each relay, it must be remembered, is attached to a separate local circuit containing battery and sounder. Therefore, if one operator presses key *A*, a sounder in circuit with relay *C* gives its message. If another operator presses key *B* a sounder in circuit with relay *D* will deliver its message. It should be understood that if both keys are worked simultaneously, the direction of the current can be reversed at will by the operator at *B*. As this is the only influence which effects the polarized relay at *D*, the system as thus presented is one in which two messages can be sent forward along the line at the same instant. This is the fundamental principle of the diplex system. Examination of key *B* will show that if the operator at *A* is holding his key and the operator at *B* reverses the current to actuate the relay at *D* the continuity of the line is not destroyed, but the relay *C* will relax for an instant, causing what is familiarly known as a *clip*. This is almost eradicated by the aid of special devices in practical telegraphy.

Duplex System of Telegraphy

In the duplex system of telegraphy it is possible to send two messages over the line, each traveling in the opposite direction. This system possesses certain essential and characteristic features which might be enumerated as follows:

1.—A differentially wound relay.

2.—An artificial line.

3.—A transmitter.

The principle involved in this system is to be able to send a message out of the station without affecting the relay installed there, yet permitting it to respond to the influence of a message or signal sent in. This seemingly difficult and paradoxical task is accomplished by the proper co-operation and relationship of the three devices mentioned above in conjunction with a storage battery.

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The differential relay, being an electromagnet with two opposite and equal windings, cannot be affected magnetically if each winding carries an equal current. If, therefore, when a signal is sent out of the station, the current it represents passes through this differential relay, then the problem resolves itself into that of securing an equal flow of electricity through each of the windings of the relay. If means are employed, through which one-half of this current goes out over the line, and the other half is directed into the earth, then the difficulty has been removed and the object of keeping the relay inoperative under these circumstances secured.

The artificial line now comes into play. It consists of a resistance equal to that of the line, and a condenser of a capacity also equal to that of the line. The current from the station is led to the point at which the two windings of the electromagnet begin, as shown in Fig.

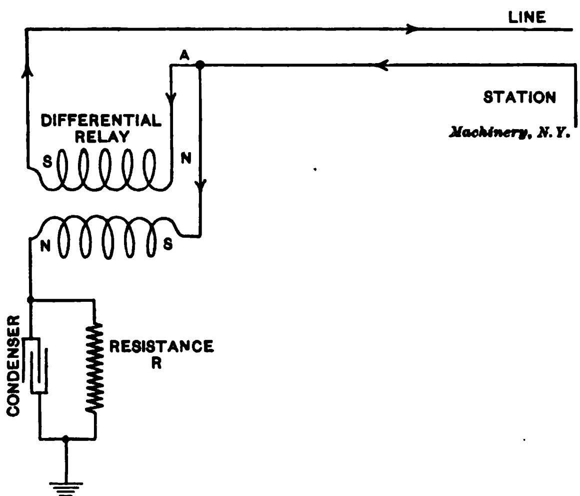

Fig. 8. Arrangement of Artificial Line in Duplex Telegraphy

8 at *A*. If resistance *R* and the capacity of the condenser are exactly equal to those of the line, then the current will divide equally at *A*. One-half will go through the relay winding and over the line. The other half will go through the relay winding into the earth. The currents being equal in each winding of the relay, it will remain unaffected when an outgoing signal is sent.

The transmitter employed in duplex telegraphy is so arranged that when the key is pressed, as shown in Fig. 9, the magnet *S* will pull the lever *D*, and thus produce a contact with lever *N* at O. This enables the current from the battery *B* to pass into the differential relay, one-half to the line and one-half to the earth. If at this moment, the distant telegrapher presses his key, then one of the coils of the differential relay will be supplied with more current than the other, and as a natural consequence of this, the relay will be operated. Its operation means the throwing in of the local circuit, and as a result the

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click of the sounder is heard. Hence, it will be seen that by means of this construction it is possible to accomplish the desired results, that is, making the relay inoperative by the outgoing current and making it responsive to the incoming signal.

The diagram in Fig. 9 should be examined in order to fully understand the paths of the various currents. When the key *K* is pressed, as already described, a negative current passes from the battery *B* through the levers *D* and *N* into the differential relay only to divide equally into the line and earth *via* the two opposite windings of the relay. A signal sent in, however, means a current in only one winding of the relay, which, of course, will force it to operate, or it means a current superposed upon the other already passing through. This last condition only exists when both keys are pressed in each station at the same time. The wire grounded at *A* serves the purpose of allowing an incoming current, whether positive or negative, to pass into

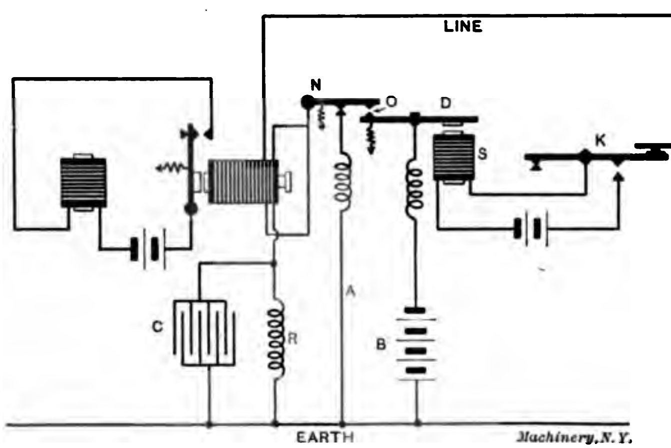

Fig. 9. General Arrangement of Duplex System of Telegraphy

the earth after magnetizing the relay. The diplex and the duplex therefore differ from each other fundamentally in the respect that in the first case both the direction and the strength of the current are controlled to operate two relays adjusted to them; while in the second case, messages are transmitted in opposite directions, by having a relay in action sensitive only to the incoming impulse, and remaining unaffected by the outgoing signals through the influence of the artificial line.

Purpose of Condenser

The introduction of the condenser in duplex telegraphy was the idea of Joseph B. Stearns, who thus, by its practical application, removed from the apparatus the false signal its absence produces. The resistance of the artificial line and line proper may be the same, but this alone would not fulfill the purpose desired. It is obvious that as the line must be charged when signalling, it is bound to discharge itself

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later and affect the service, that is, the line will act as a condenser, the charging of the line when signalling presupposing a subsequent discharge through the instruments. In order to balance its effect, it is necessary to place a condenser in the artificial line as well as the resistance. The capacity of the condenser and the ohmic resistance of the artificial line must at all times be equal to the capacity and the resistance of the line proper, if the sending of messages is to be made possible with equal facility from each end of the line. As the capacity and the resistance of the line proper differ with the weather condi-

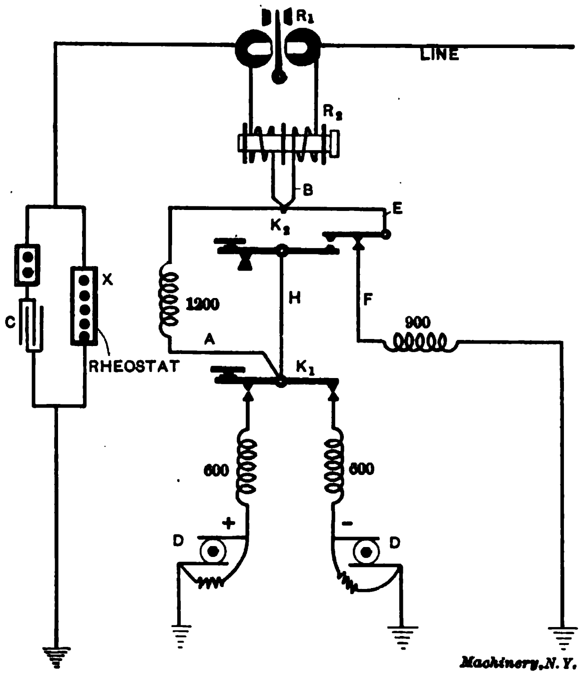

Fig. 10. General Arrangement of Quadruplex System of Telegraphy

tions, adjustment must be made of the resistance and capacity of the condenser in the artificial line. The term applied to these adjustments is "balancing." The adjustments must be made every day, particularly if the weather is changeable.

Quadruplex Telegraphy

By means of quadruplex telegraphy, two messages can be sent from each end at the same time. Altogether, four different signals traverse the wire at one time without interference. The accomplishment of this, it is evident, means the use of two relays at each of the stations receiving the signals. It is also obvious that when two signals are sent simultaneously from one station the relays of said station must not be actuated by the current. This proposition is carried out in practice by the use of two differential relays at each station. These relays

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are, respectively, neutral and polarized, and operate in conjunction with an artificial line. In addition each station is provided with two keys of the characters previously described in connection with diplex telegraphy. One is used for sending a comparatively powerful current into the line, the other for reversing the polarity of the line.

In Fig. 10 the quadruplex system is shown operated by means of currents generated by dynamos *D*. These take the place of the batteries, and have proved themselves to be far more convenient. At the dynamos opposite poles are connected to the line with two 600 ohm resistances in circuit. The description referring to this diagram, as given by Franklin Leonard Pope in his work entitled "Modern Practice of the Electric Telegraph," is as follows: "K_1 is the pole changing transmitter and K_2, the single current transmitter, which for simplicity are shown in the diagram as keys, but which are in practice operated by electromagnets, local batteries and independent keys. When the apparatus is at rest, the current from the negative dynamo traverses a resistance coil of say 600 ohms, inserted to avoid danger of short circuit, to the rear contact of the pole changing key K_1; thence through wire *A* and the 1200 ohms resistance to point *B*, where it divides into three portions; the first portion going to the line and distant station, the second through the artificial line, including rheostat *X* to the earth, and the third through the wire *E*, the normally closed rear contact of the single current key K_2 and a rheostat of say 900 ohms to the earth. If, for example, therefore, we assume the resistance of the main and artificial line to be 3600 ohms each, it follows from the law of the distribution of currents in branch circuits that two-thirds will return to earth through wires *E* and *F*., one-sixth will go to the main line and one-sixth to the artificial line.

"If now the key K_2 be depressed in order to send a signal, a direct connection will be formed between key K_1 and the point *B* through wires *H* and *E*, shunting the 1200 ohm coil in wire *A*. At the same time the wire *F* will be opened, and the whole current will divide at the point *B*, half going to the main line and half to the artificial line. It follows, therefore, that with the several resistances in the ratios shown, the current sent to line by the key K_1 when key K_2 is depressed will be three times as strong as when the latter is raised, and this will be equally true whether the current sent by key K_1 be positive or negative. A computation of the effects of the several resistances will also show that when an arriving current reaches the point *B*, the resistance which it has to encounter in passing thence to the ground is the same whether the key K_2 be depressed or raised. When the key is depressed the resistance is only that of one or the other of the 600 ohm coils between the key K_1 and the dynamos; when raised, it is the joint resistance of one coil of 600, plus the coil of 1200 (a total of 1800) in one branch, and the coil of 900 in the other branch, the joint resistance of the two being 600, the same as in the first instance. The relays R_1 and R_2 at each station, being both differential, are not affected by outgoing currents, whatever may be the strength or the polarity of such currents."

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CHAPTER II

WIRELESS TELEGRAPHY

In speaking of the origin of wireless telegraphy, it is necessary to begin at that point in the history of the discoveries in electricity which might be properly called the first suggestion. On this score many arguments may arise, presented on the one hand by the scientist and mathematician, and on the other hand by the practical inventor. It is generally acknowledged, however, that the first correct analysis of the conditions and phenomena which gave rise to what was later called wireless telegraphy was made by Hertz of Karlsruhe, Germany, who in 1888 succeeded in producing electric waves which followed the known laws of light waves. The theoretical system of Maxwell, who determined mathematically the relations between the varied phenomena produced by electric and magnetic forces guided Hertz in his experiments; and then again, the basis of Maxwell's mathematical investigations was a long series of epoch-making experiments made by Faraday, who in 1845 demonstrated experimentally that electric and magnetic forces were transmitted through the same medium as light. Going still further back, we find that the primary principle upon which the modern invention of wireless telegraphy is based was annunciated in 1678 by Huygens, of Holland, who first voiced the idea that all space not taken up by matter was filled by a subtle substance which he called ether, and which made it possible to account in a logical manner for the various phenomena of light.

It is quite evident that while the study of wireless telegraphy is a practical proposition, it is necessary to examine to some extent the principles involved in the experiments which led up to its practical application, in order to understand more fully the conditions and limitations of this new art of transmitting messages by means of electricity. During experiments conducted for the purpose of ascertaining the laws according to which electric waves move through space, Hertz discovered sparks at various points in his circuits which were strongest where a wall seemed to act as a reflector. He was able to trace the reflected waves and to measure them, and arrived at the astounding conclusion that conductors carrying an oscillating current were throwing out into space waves in every respect similar to light waves, although invisible. The reason why these waves are not visible to the eye is because they are longer than the light waves and, therefore, do not affect the eye. They are propagated through space, however, at a velocity equal to that of light.

A diagrammatical view embodying the main features of the apparatus which Hertz used in producing and demonstrating the existence of electric waves is shown in Fig. 11. The main apparatus shown is the wave-producing or sending apparatus, while the ring shown at *H*

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is the receiver, commonly called resonator. The sending apparatus consists of an induction coil *A* receiving its current from a battery *B*. The circuit can be closed and opened at will at *C*. The terminals of the induction coil at *D* are connected to two brass spheres *E*, which in turn are attached to the metal sheets *F* by means of brass rods *G*. This latter part of the instrument is called the oscillator, and from it the electric waves are propagated. In order to produce electric waves it is necessary to discharge static electricity from the oscillator formed by the oppositely located metal conductors *F*, separated by a spark gap at *K*. The oscillator is charged by the current from the induction coil when the circuit is closed at *C*. When sparking takes place between the metal spheres *E*, the opposite sides of the oscillator discharge into each other, thus equalizing their difference of potential. When sparking occurs, electric waves are produced which are propagated through space. As soon as a series of sparks have been emitted, the oscillator must be recharged before another set of sparks and waves

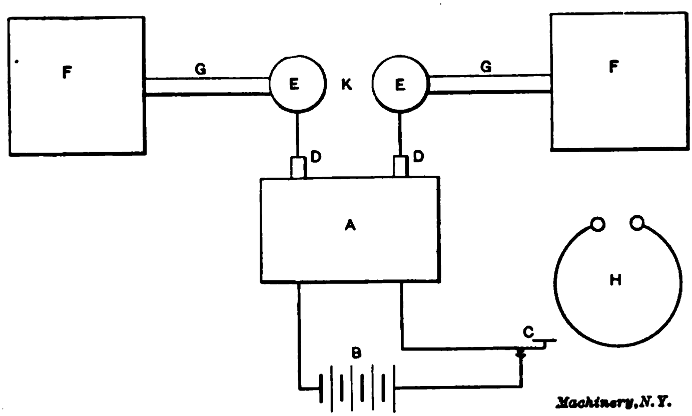

Fig. 11. Main Features of Hertz Apparatus

can be produced. The charging of the oscillator is done automatically through the induction coil connections. As soon as the oscillator has been discharged through the spark gap, the high tension current from the induction coil immediately recharges the oscillator to its maximum capacity, and the cycle of operation is repeated.

When the apparatus is operated, that is, when the circuit is closed at *C*, thus charging the oscillator, the presence of electric waves can be shown by the resonator already mentioned. When the electric waves impinge upon this resonator, the passage of a small spark across the air gap between the small knobs indicates the presence of electric waves. The simple apparatus described contains the primary and necessary elements of a wireless telegraph outfit. Improvements were made upon this apparatus by Branly, of Paris, who found in 1890 that metal filings enclosed in a tube were extremely sensitive to the pres-

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ence of weak electric waves, and based the construction of the coherer or "wave detector" (which will be described in detail later) on this fact. The instrument was further improved upon by Popoff, a Russian investigator.

The principle of the Popoff apparatus is shown in Fig. 12. At *A* is shown a coherer or wave detector and an electric bell, the hammer *B* of which serves the purpose of tapping the wave detector after it has been influenced by the electric waves, thus neutralizing it so that it will again be ready to fill its purpose when the next signal is received. A sensitive relay is placed at *C* and a local battery at *D*. It will be seen that one of the terminals of the coherer is connected to a metal rod *E* which extends into the air, while the other terminal is connected at *F* with the earth. This apparatus contains all the elements of the wireless telegraph receiver.

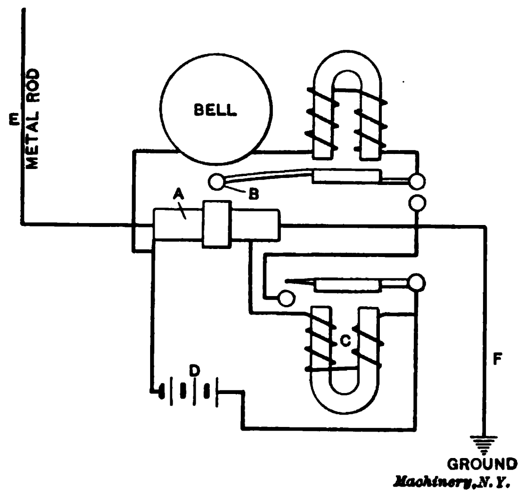

Fig. 12. Principal Features of the Popoff Apparatus

Finally Marconi in 1895 began experiments with the apparatus thus far developed, with a view to long-distance transmission of messages. He attained a considerable degree of success, so that in 1897 wireless telegraphy might be said to have entered upon its commercial stage. Since that time many improvements have been made by a great number of scientists and practical inventors. These improvements, however, have introduced no new principles, but merely have been concentrated upon eliminating such defects as were apparent in the earlier efforts. With due respect for all the workers who have aided in developing wireless telegraphy to its present day state, however, the honor of the most important scientific discovery is due to Hertz, and the credit for the development of his idea in a practical manner, making commercial application possible, belongs to Marconi.

The principal advantage of the Marconi system, as compared with those that had been previously devised was that in his transmitter he

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connected one end of the oscillator to a wire suspended in the air, and the opposite end of the oscillator to the earth, as indicated in Fig. 13. He found that in doing so the electric energy was radiated in the form of electric waves over much greater areas than was possible when using an oscillator of the Hertz type. The receiver of the Marconi system also had one of the connections extending into the air and one leading to the ground, the same as already shown in Fig. 12, illustrating the Popoff instrument.

Fundamental Principles of Wireless Telegraphy

The fundamental principles of wireless telegraphy may be summed up as follows: The transmission of messages is accomplished over long distances by the projection of electric waves through space. These

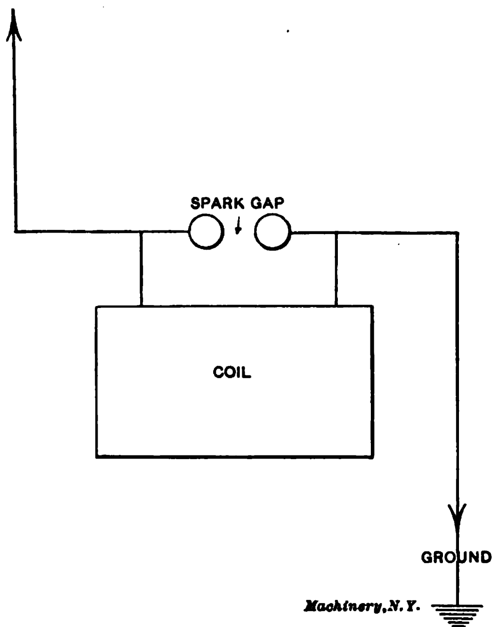

Fig. 13. Arrangement of Marconi Oscillator

electric waves are produced between the discharge knobs of an induction coil. The principle of electric magnetic induction is employed in creating the high pressure or voltage required for this apparatus. The waves sent out may in many respects be likened to the sending out of a powerful beam of light from a search lamp of great capacity. The waves projected from the electrical apparatus in this case, however, are not visible. They are transmitted through the ether, a substance of which practically nothing is known, but the existence of which is acknowledged because through it all energy is transmitted. In this respect it is of particular interest to electricians, because it seems particularly adapted for carrying electrical energy. The electric waves thus sent out are received by an apparatus consisting of a coherer, or

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wave detector, a relay, and a sounder or writing apparatus, the latter of which details are constructed practically on the same lines as the ordinary mechanism for receiving telegraphic messages transmitted by wire.

A mistaken conception seems to exist regarding the employment of electric waves for signalling purposes in wireless telegraphy. It should be understood that the electric wave itself does not give the direct signal. This is impossible on account of the exceptionally delicate nature of the electrical manifestations of the electric wave at the receiving station. For this reason a device is added to the devices in use for ordinary telegraphy in the form of an electric wave detector or coherer. The function of the electric wave is simply to act as a primary means for setting into operation the apparatus which gives the actual signals through the aid of a more powerful current than that transmitted through the ether. In a sense, the wave-detector may be considered as filling the same function with relation to the relay of the wireless receiving station, as the relay itself fills with relation to the sounder in the ordinary telegraph station.

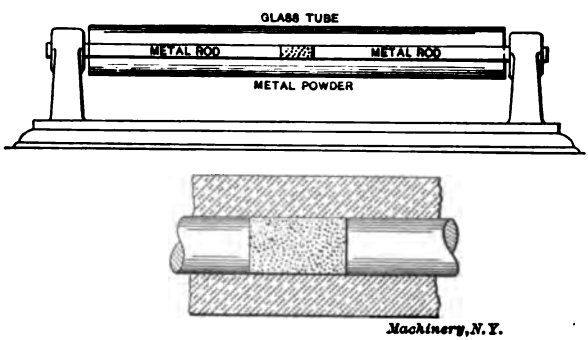

Fig. 14. General Arrangement of Coherer

The coherer generally consists of a tube of glass with a metal plug at each end, as indicated in Fig. 14. A small amount of metallic powder or filings is enclosed between the plugs. The theory upon which the application of this device is based is that the conductivity of finely granulated conducting substances is very high under certain conditions. Referring to this S. P. Thompson says: "The conduction of powdered metals is remarkable. A loose heap of filings scarcely conducts at all, owing to the want of cohesion, or to the existence of films of air or dust, but it becomes instantly a good conductor if an electric spark is allowed to occur anywhere within a few yards of it. The resisting films of air are broken down by minute internal discharges in the mass. A very slight agitation by tapping at once makes the powder non-conductive."

This condition has been made use of for producing one of the most important parts of the wireless telegraph outfit. A small amount of metallic powder, usually nickel with a touch of silver, is contained

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within a small glass tube with metal pins at the ends, as mentioned. The device is placed in series with a few cells of battery and a telegraphic relay. The coherer will not operate under normal conditions, but the presence of electric waves sets it immediately into action. The electric waves impinge upon the metallic filings producing between them minute sparks. Over the paths thus provided the battery current instantly passes and actuates the relay. The relay then in turn operates the sounder, and thus a signal is transmitted through the air without the aid of a transmitting wire.

The current would continue to flow and the relay would remain in action if some means were not provided by means of which the metallic powder in the coherer is disarranged so as to cease to act as a conductor. This process is called de-cohering, and consists simply of tapping the coherer after the receipt of a signal so as to make the metallic powder non-conductive. This tapping is done automatically by means of a small vibrating hammer similar to that used in an electric bell. In fact, a small bell without the gong will perform this function satisfactorily if so connected that its hammer just touches the glass tube of the coherer. In Fig. 15 is shown a diagrammatical view of the receiving end of a wireless telegraph outfit. The coherer, the telegraph relay, the sounder, and the two sets of batteries, are clearly indicated.

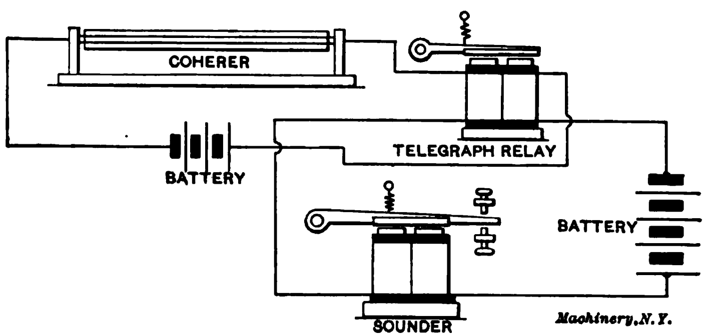

Fig. 15. Arrangement of Receiving End

A diagrammatical sketch of the apparatus for producing the waves is shown in Fig. 16. This apparatus consists primarily of a spark or induction coil. The spark coil is made up of primary and secondary windings as shown, and provided with a vibrator by means of which the current in the primary coil is interrupted, and a condenser. The primary coil receives the electrical energy and transforms it into magnetic energy. The vibrator interrupts the current entering the primary coil, thus permitting induction to take place between it and the secondary coil. The secondary coil has magnetic energy induced in it by the primary and transformed into a high-pressure current. A condenser is used as shown, made in the customary manner of tin-foil and paraffine paper. It is placed in the break of the vibrator for the purpose of taking up the energy that would otherwise be wasted in self-induction.

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When the spark coil is set into operation, what might be termed a torrent of sparks passes between the discharge knobs. The size of the knobs, the gap between them and the dimensions of the coil determine the reaching power of the waves. When a signal is to be sent the sparks are allowed to pass between the knobs by closing a switch. Then at the receiving end the coherer is affected by the waves propagated. The signals sent are either long or short, representing dashes and dots the same as in the regular Morse code, the sounder or ink-writer ultimately delivering the message. To receive the waves towers or metallic poles are employed. These are usually called antennae. The coherer is attached to the top of these and is, therefore, made more readily sensitive to the electric vibrations in the ether.

The devices described above constitute the very first and simplest types of wireless telegraph outfits. Of course, the wireless telegraph is constantly being improved upon, and a number of features have been introduced which were not used in the first apparatus. The principles, however, are more clearly exhibited in this apparatus, and for the elementary purpose of this treatise it would not be advisable to con-

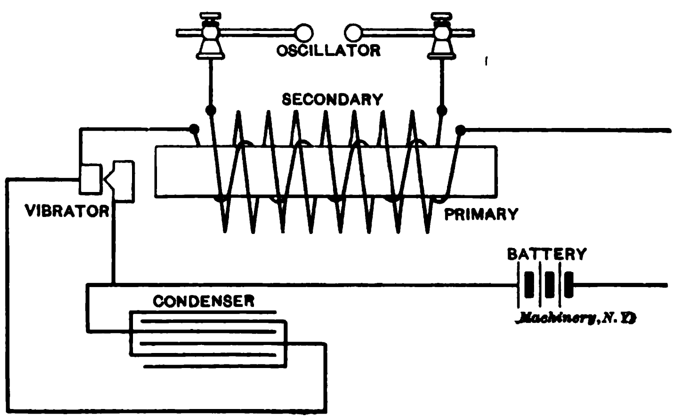

Fig. 16. Wave Producing Apparatus

fuse the subject by introducing descriptions of the many different systems that have been proposed and introduced from time to time. Among the most successful systems containing improvements on the original Marconi system may, however, be mentioned Oliver Lodge system, the Slaby-Arco system, the Braun-Siemens system, the Fessenden system, the American De Forest system, the Branly-Popp system, the Lodge-Muirhead system, and the Bull system.

Having described the principal features and action of the wireless telegraph system it may not be out of place to describe more in detail some of the more important parts of the sending and receiving apparatus.

The Induction Coil

The purpose of the induction coil is to receive a low-voltage direct current and transform it into a high-voltage current. The induction

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coil is made up of an iron core usually formed of a number of wires of soft iron. Around this core is wound two layers of heavy wire called the primary coil. This primary coil connects on the one end directly with the source of energy, whether it be a battery or a dynamo, while at the other end the wire is connected with the vibrator arranged for automatically opening and closing the circuit. The vibrator in turn is connected with the opposite pole of the battery or the dynamo. A condenser, as already mentioned, is connected with the vibrator in such a way that when the contacts of the vibrator are closed the condenser is connected in shunt, but when the contacts are open the condenser is in series with the primary coil circuit. (See Fig. 16.) The secondary coil is wound outside of the primary, carefully insulated from it. It consists of several thousand feet of very fine wire. The ends of the secondary are connected with the arms of the oscillator as shown in Fig. 16.

When a current is sent through the primary coil, and frequently interrupted, it will produce by induction a current in the secondary coil. The interruptions of the current are repeated automatically several hundred times a minute. It is necessary that the current be thus interrupted, because if an uninterrupted direct current flows through the primary, no current would be induced in the secondary. It is the frequent interruption of the current that makes possible the induction of current in the secondary. The current which flows through the secondary is an alternating current, because when the current flows through the primary it magnetizes the core of the induction coil, and current is induced in one direction in the secondary. When the vibrator breaks the circuit, a current is induced in the opposite direction. In this way a high-tension alternating current is produced in the secondary coil, and can be utilized for charging the oscillator and producing the sparks due to which the electric waves are sent forth.

An ordinary transformer, that is, an instrument by means of which an alternating current of low voltage is transformed into alternating current of high voltage, is used in some wireless apparatus in place of the induction coil. In this case the source of electric energy must be an alternating current generator.

The key used in the sending apparatus is constructed in a manner similar to an ordinary telegraph key, but is very much larger, due to the fact that the currents used in the apparatus are of very much greater power than in the ordinary telegraph. It is not unusual that the connections to be made and broken convey currents in excess of one horsepower.

The distance between the two knobs of the spheres of the oscillator between which the spark is formed, can usually be adjusted to suit the requirements.

The Wave Detector and Relay

The ordinary coherer in which metal filings are used has already been partly described. It usually is provided with two silver conductor plugs with platinum wire terminals. The air is exhausted from the space between the plugs, which is filled with filings made with a

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coarse file, usually in the proportions of 90 per cent of nickel and 10 per cent of silver. A special type of coherer is termed the auto-coherer, which is so constructed that it needs no tapping to return it to its normal resistance after it has been influenced by the action of electric waves. These coherers are restored automatically to their non-conductive state. The polarized relay described in the previous chapter is the only one which is sensitive enough to be used for long-distance wireless telegraphy.

The De-Coherer

The de-coherer or tapper for restoring the filings in the coherer to their original or non-conductive state resembles an ordinary electric bell, except that the vibrations of the hammer are not as rapid. Usually the device is so constructed that the strength of the stroke of the hammer can be adjusted to suit conditions.

For receiving the message modern systems use a telephone receiver instead of the Morse sounder or ink-writer.

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CHAPTER III

THE TELEPHONE

The transmission of speech by electricity is one of the most interesting exhibitions of the law of the conservation of energy. The common popular idea that the sound produced at one end of the telephone circuit actually travels over that circuit in order to be heard at the other end is, of course, erroneous. In fact the actual sound produced at one end of a telephone circuit travels no farther than it would if the telephone apparatus were not present, but the energy produced by the sound is changed or transformed in the telephone apparatus into electrical energy which travels over the wire and which again is retransformed by the apparatus at the other end of the line into sound. When speaking, a series of vibrations in the vocal chords create sound waves or, rather, air waves, which represent the energy that is to be transformed into electrical energy in order to permit of transmission over a long distance. The actual telephoning, hence, consists of three processes, first, the directing of the voice into a sending instrument, second, the conducting of the voice equivalent transformed into electrical energy over the line, and, third, the receiving of the voice equivalent in the form of electrical energy and transforming it into sound energy at the end of the line. The sending instrument is called the transmitter, the conducting circuit or wire is called the line, and the instrument which changes the electrical energy into sound at the further end of the line is called the receiver, these names indicating clearly the functions of the various devices. It is the object of the present chapter to describe the apparatus by means of which the transmission of speech by electricity is accomplished.

Historical

In 1868 Philip Reis, of Friedrichsdorf, Germany, invented the first apparatus by means of which sound could be transmitted to a distant point by the aid of the electric current. The name telephone was given to this apparatus by the inventor. His invention, however, was not of so practical a nature as to become commercially useful. In 1876 patent specifications were filed simultaneously at Washington by Alexander Graham Bell and Elisha Gray, for a speaking telephone, and in February, 1876, a patent was granted to Bell. The question of the priority of the two inventors caused litigation which ended in a compromise, consisting in the forming of a company which brought out the inventions of both the inventors. The invention of the telephone, however, is generally credited to Bell, and apparently justly so, both from a legal and a scientific point of view.

Principle of Transmission of Sound by the Telephone

As already mentioned, when sound is produced, vibrations are set up in the air. The simplest kind of vibration, and one the nature of

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which is most easily understood, from the fact that it is most commonly produced by the vibrations of a metal string, is that of a musical tone. As an example, it may be mentioned that the musical tone known as middle C is produced by 256 vibrations per second. The vibrations produced by the human voice are much more complicated in their nature than those of a musical instrument, and due to this fact, the very earliest attempts for transmitting sound by means of a telephone apparatus were capable of reproducing musical tones, but could not transmit and reproduce the sounds of the human voice.

The simplest form of telephone, the form, in fact, on which the original invention of Bell was founded, is illustrated diagrammatically in Fig. 17. In this simple type, the principle of transmission depends exclusively upon electromagnetic induction. The instruments at each end of the circuit are the same, so that in this case there is no difference in construction between transmitter and receiver. Assume, however, for purposes of explanation that *A* is the transmitter and *B* the receiver. At *C* and *D* are shown two permanent bar magnets, wound on their ends with a number of coils of fine insulated copper wire, as shown at *E* and *F*. At *G* and *H* are shown elastic disks made of very thin sheet iron. These disks vibrate when

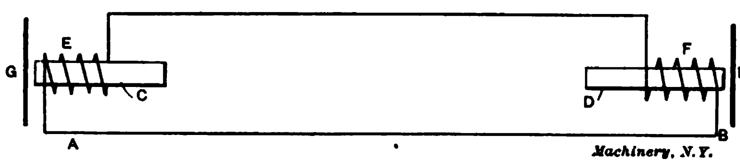

Fig. 17. Principle of Simplest Form of Telephone

sound or air waves strike them, due to the voice being directed into the instrument holding them. These disks are commonly known as the diaphragms.

Now assume that sound is to be transmitted from *A* to *B*. The permanent magnet *C* sets up a magnetic field or lines of force, and as the diaphragm *G* offers a path for these lines of force having less resistance than the surrounding air, a great number of the lines of force will pass through it. Now when the voice is directed against the diaphragm *G*, the vibrations in the air will cause the thin sheet steel disk to vibrate. When the disk during its vibrations comes closer to the end of the magnet, a greater number of lines of force pass through it, and when it recedes from the magnet, a smaller number of lines will pass through it. By means of this action a less or greater number of lines of force will pass through the coil *E*, and due to this, an alternating current will be induced in it, the strength of which will be proportional to the rate of change in the number of lines of force. The alternating currents produced in coil *E* pass through the line to the coil *F* wound around the magnet *D*, at the receiving end *B* of the line. Due to electromagnetic action, the currents set up will either add to or subtract from the original strength

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of the magnet *D*. When they add to the strength of the magnet, the diaphragm *H* will evidently be attracted, and when they subtract from or decrease the strength of the magnet, the diaphragm moves away. It is obvious that on account of this action the diaphragm *H* will be caused to vibrate exactly in accord with the diaphragm at the transmitting end *A*, and as in this manner similar vibrations are set up in the air, the sounds producing the vibrations at the transmitting end will be reproduced by the diaphragm at the receiving end, although not with the same strength.

The simple arrangement described has been somewhat modified in the modern commercial telephone. The principal differences are that there is a special transmitter at each end of the line, separate from

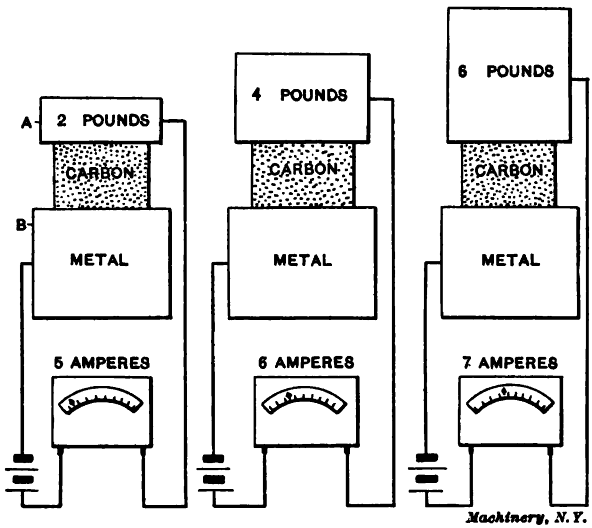

Fig. 18. Diagrammatical Illustration of the Effect of Pressure on the Resistance of Carbon

the receiver, and that this transmitter is constructed on a principle entirely different from the receiver. The principle of the modern receiver, however, is essentially the same as that explained above.

The Telephone Transmitter

In a telephone based on the simple principles just outlined, where the same instrument is used for transmitter and receiver, and the whole action is due to electromagnetic induction, the strength of the current for lines of even moderate length is so diminished, due to the line resistance, that satisfactory results are not obtainable. For this reason it was found necessary to devise an instrument which would vary the current in exact accord with the sound waves and which current could, through the means of an induction coil, induce such a current in the coil of the receiving telephone that the sound would be distinctly reproduced at the other end of the line. Edison, in 1877,

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conceived the idea of utilizing carbon as an element in transmitter construction, basing his investigations along these lines upon the fact that the resistance of carbon to the flow of electric current depends upon the mechanical pressure exerted upon the carbon.

The effect of pressure on the electric resistance of carbon is diagrammatically illustrated in Fig. 18, where an electric circuit is shown connected to two metal blocks separated by a piece of carbon. The metal block on the top exerts a different pressure on the carbon in the three instances shown, and as the electric resistance decreases with increasing pressure, a current of different strength will flow through the line in each case. The action of the telephone transmitter or microphone depends upon the same fact: if the resistance of the circuit is increased, the current will decrease, and if the resistance is decreased, the current will increase, the variations in resistance being produced by varying the pressure on the carbon placed between the electrodes, that is, the terminals or parts to which the ends of the electric current carrying wire are connected, as *A* and *B* in Fig. 18. On this basis three different types of transmitters have been constructed. In one type only one carbon contact is employed for varying the resistance; in another type a number of contacts are used; and in a third type granulated carbon is employed, thus producing a very large number of individual contacts.

The Blake Transmitter

In Fig. 19 is shown a diagrammatical section of the Blake telephone transmitter, which is an example of the type of transmitter using a single carbon contact for varying the resistance. In this device the diaphragm is shown at *A*. This diaphragm is similar to that used in the receiver in the original type of telephone. All transmitters, of whatever type, use a diaphragm of practically the same kind. *B* and *C* are two flat springs, and *D* is a piece of carbon, usually called a carbon button, which rests in holder *E*. The diaphragm *A* is supported by a rubber ring. It is held in place by two springs called damping springs, which are not shown in the illustration. The object of these springs is to check the vibrations of the diaphragm as soon as the vibrations have filled their purpose of producing undulations in the electric current. On the spring *B* is mounted one of the electrodes, in this case a platinum pin. One end of this pin rests against the center of the diaphragm, and the other end rests against the carbon button *D*, which forms the other electrode, and which together with its holder *E* is mounted on spring *C*. The springs are so adjusted that the carbon button bears lightly against the end of the platinum pin. The spring *B* acts in the direction of spring *C*, that is, it has a tendency of pulling the platinum pin away from the diaphragm, but this tendency is counteracted by spring *C*, which is stronger, and which exerts a force in the opposite direction and thus keeps the platinum pin in contact with both the diaphragm and the carbon button.

Being mounted on springs, it is evident that both the electrodes

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can move freely when the diaphragm vibrates. The carbon button, however, being mounted on a stiffer spring and being held in a comparatively heavy socket, cannot respond as quickly to the vibrations as does the platinum pin mounted on a very sensitive spring. Vibrations in the diaphragm, therefore, produce a variation in the pressure between the platinum pin and the carbon button, thus varying the resistance at the point of contact and permitting a current of varying strength to pass through. The two springs *B* and *C* are insulated from each other, so that the current is led into the platinum electrode by the one and from the carbon electrode by the other. The ends of the springs, of course, are connected to the wires passing through the batteries which furnish the current, and around the induction coil where the current passing through the line, and to the receiving end,

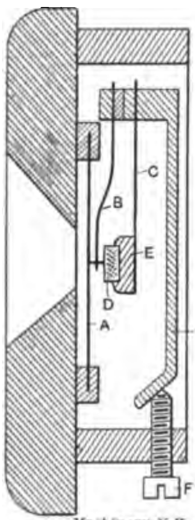

Fig. 19. The Blake Transmitter

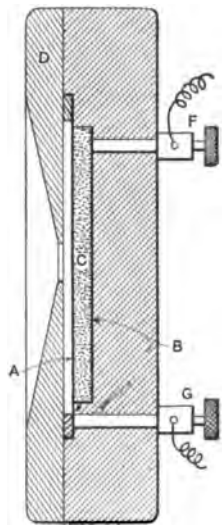

Fig. 20. The Hunnings Transmitter

is induced, as will be described later. The mechanical pressure between the platinum pin and the carbon button can be adjusted by means of screw *F*, which bears against the bent-up end of a lever *G*.

The Blake transmitter is used to some extent at the present time and works fairly satisfactorily on lines of moderate length. Its disadvantages are that it is difficult to keep in adjustment, and that it is not adapted for long-distance work, because of not being sensitive enough. The type of transmitter mentioned above which uses several carbon button contacts is not used very much, and is, therefore, of no specific interest. The third form employing granulated carbon, however, is rapidly replacing the other types and must be accorded an extended description.

The Hunnings Transmitter

A diagrammatical section of the Hunnings transmitter is shown in Fig. 20. In its simplest form this transmitter consists of two insu-

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lated plates *A* and *B* of conducting material, these plates forming the electrodes of the transmitter and having a space between them which is filled with granular carbon as shown at *C*. The plate *A* serves also as the diaphragm, and is clamped between the body of the transmitter and the cap *D*. The two electrodes are connected to the wires of the battery circuit by binding posts *F* and *G*, as indicted. When sound waves impinge upon the diaphragm, vibrations are set up, and the pressure upon the great number of contact points between the granular carbon and the metal plates causes a current of varying strength to flow from one electrode to the other. A greater variation of resistance is produced in this type of transmitter than in the Blake transmitter previously described, and heavier currents can also be used.

Improvements have been made on this transmitter, but the improved types work on the same principle as that described, the improvements being merely in details. The Hunnings transmitter operates in a satisfactory manner over long distances. The only disadvantage with granular carbon transmitters is that there is a decided tendency on the part of the granular carbon to pack together. The packing in transmitters is due to the expansion of the carbon granules by the heat generated by the current and also by the heat of the breath of the user of the instrument. It is evident that if the granules have no space in which to expand, and particularly if the expansion of other parts as well tends to decrease the space in which they are contained, then they will pack solidly together. When in this condition the sensitiveness of the device is seriously impaired. In fact, when the carbon becomes solidly packed together the transmitter is useless for its purpose. This packing can be overcome by striking the side of the transmitter a sharp blow by the hand, but this practice cannot be recommended, because, as one authority on this subject says: "The hands of the layman are not conducive to the longevity of the instrument."

In modern transmitters the tendency to packing is, therefore, reduced to a minimum by the design of the device itself, the "solid back" transmitter being devised for this purpose. The principle by means of which packing is prevented in this instrument is as follows: An annular space is provided between the periphery of the electrodes and the inside surface of the chamber in which the electrodes are contained. A certain number of the carbon granules are contained in this annular space, but it is not quite filled to its full capacity. The granules in the annular space are not heated when the current passes, and hence do not expand. When the granules which are located directly between the electrodes become overheated, they can expand into the annular portion, hence preventing packing between the electrodes. The transmitters used at the present time are nearly all made according to the principles outlined for the solid back type of transmitter.

The Receiver

The telephone receiver, of practically the same type as the one now used, except for improvements in details, was first exhibited publicly

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at the Centennial Exposition in Philadelphia in 1876 by Alexander Graham Bell. As already mentioned, speech can be both transmitted and received by this instrument, but it is not satisfactory when used as a transmitter. The essential parts of the receiver are a magnetized steel bar, a coil of fine copper wire, and a diaphragm of thin sheet steel. Two forms of receivers are in common use, one being termed a single-pole and the other the bi-polar type.

The single-pole type is represented by the Bell type of receiver shown in Fig. 21. The outer casing of the receiver is made of hard rubber, so as to be thoroughly insulating. Inside of this casing is placed a laminated bar magnet *A*. At one end of the magnet is a pole piece of soft iron *B* and at the other end a block *C*. On the pole piece *B* is placed a coil *D* of fine insulated copper wire, which is connected with the line through wires *F* leading to the binding posts *G* at the end of the receiver. On the other end of the receiver is a cap *H* which supports the diaphragm of the instrument; as indicated, this is placed immediately in front of the pole piece of the magnet so that the part of it which is opposite the pole piece is free to vibrate. The coil *D*

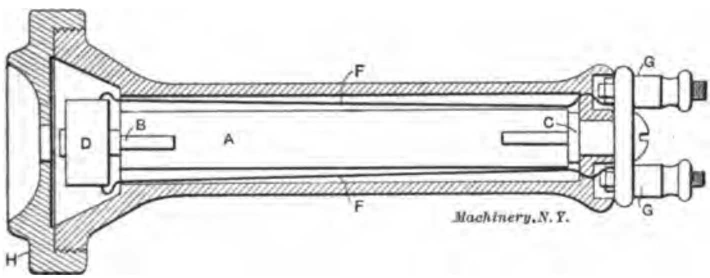

Fig. 21. Single-pole Type Receiver

on the pole piece at the front end of the receiver is made of a great many turns so as to be sensitive to the slightest change in the current passing through it.

When the induced current in the line passes through the coil, it increases or decreases the magnetism of the bar magnet as already described in the first part of this chapter, thus producing vibrations in the diaphragm on account of the greater or less force by means of which the diaphragm is attracted to the magnet, the result of it all being the duplication of the sounds of the voice entering the transmitter at the other end. The whole telephone system has been likened to an electric power transmission plant. At the transmitting end the mechanical energy in the form of air vibrations is absorbed and transformed into electrical energy. This electrical energy is conducted to another point and finally there retransformed into mechanical energy. Of course, with the transmitter of the modern type, the primary current is supplied by a battery and not produced directly by the energy of the impinging air waves.

The single-pole receiver is at the present time being more and more replaced by the bi-polar receiver, which does not differ from the other

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in principle, but simply in the fact that the permanent magnet of the receiver instead of being straight is constructed as a horse-shoe magnet. In this way both poles of the magnet are placed in a position where they can act on the diaphragm, thus increasing the strength of the magnetic field and consequently producing an instrument which is more sensitive and efficient. A pole piece of soft iron is fastened to each end of the horse-shoe magnet and a coil of insulated copper wire is placed on each pole piece. The bi-polar receiver is always used in long-distance telephone systems, and to a considerable extent for local systems.

The Induction Coil

The success of the telephone system depends upon the employment of the induction coil, by means of which the voltage of the out-going current is raised above that of the transmitter, and its character changed from that of a direct-current into an alternating wave of electricity. The transmitter is mounted in series with a local circuit. containing a battery, and passing around the induction coil as the primary winding. The receiver is placed in the circuit containing the line, and the fine wire secondary winding of the induction coil. The principle of the action of the induction coil was described in the previous chapter: two coils are mounted on a soft iron core; one of the coils carries the current which is produced by the local battery and passes through the transmitter; the current in the other coil results from the pulsating movement of the current in the first coil.

The principle of the induction coil in telephony was first introduced by Elisha Gray, the object being to avoid the necessity of using too powerful a current in the transmitter. In this way the transmitter can be used in series with a low-pressure current, produced either by a battery or obtained from a storage battery charged by a dynamo. As the current which proves most satisfactory in the receiver is an alternating current, the use of the induction coil fills the requirements very satisfactorily, because by means of the induction coil the direct current of the primary circuit containing the transmitter is changed into an alternating current. The ordinary induction coil for telephone use consists of 200 turns of No. 20 Brown & Sharpe gage wire, wound in two layers around the core. This wire constitutes the primary coil, and around this is wound the secondary coil, which consists of about 1,500 turns of No. 34 Brown & Sharpe gage wire, also wound in a double layer. By this means the electromotive force of the induced current in the line is raised to a considerable height, so that the resistances are more easily overcome and the effect in the receiver becomes great enough to distinctly reproduce the speech.

The Complete Telephone Circuit

Having described the various instruments used for a telephone system of a simple type, we are now ready to examine the condition of a complete telephone circuit. A diagrammatical view of a complete circuit is shown in Fig. 22, where the various elements are indicated in a manner making it easy to trace the different circuits. The cir-

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cuits consist of a transmitter and receiver at the end of each line, the transmitters being in a local circuit supplied with current from batteries *A*, while the receivers are on the line circuit, the current of which is produced entirely by induction in the induction coils *B* and

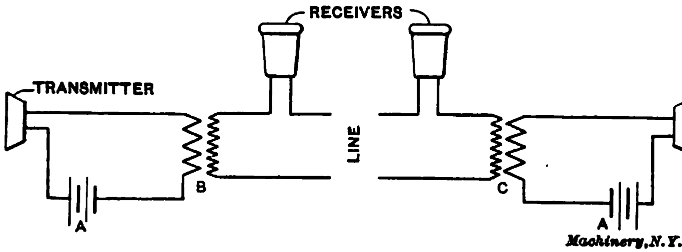

Fig. 22. Diagrammatical View of Complete Telephone Circuit

C. From what has previously been said about the construction and action of the various instruments making up the complete system, its action is easily understood without further explanation.

While, however, an arrangement such as shown will serve to transmit and receive messages, it would not make it possible to call the person or station one desires to speak to, and for this reason it is also necessary to equip the installation with some kind of a calling device. For this purpose the magneto-generator is ordinarily used. Although the telephone systems in large cities, for example in New York, dispense with the necessity of employing a magneto for ringing up a

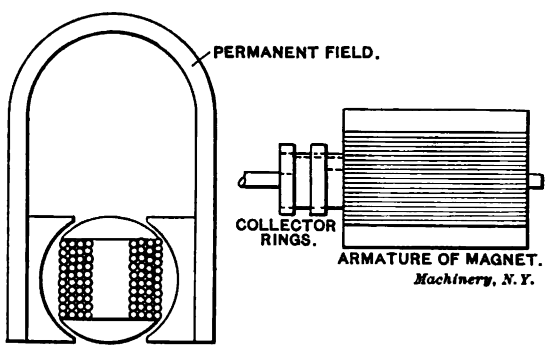

Fig. 23. Principle of Magneto-generator

subscriber, still the magneto call-bell is required for signalling from the exchange itself to a subscriber. In this case the subscriber signals "central" by merely lifting the receiver off the switch-hook, but "central" signals the desired number by ringing the subscriber's bell.

The magneto-generator usually consists of a generator having permanent field magnets and a small shuttle armature wound with many turns of fine copper wire (as shown diagrammatically in Fig. 23) and producing an alternating current. The armature of the magneto-generator can be rotated at a very high speed by means of a small

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pinion mounted directly on the armature shaft, and meshing with a larger gear mounted on a shaft on which in turn the hand-crank for the operation of the instrument is placed. The magneto-generators used are constructed so as to ring through 1000, 5000, 10,000 or even 50,000 ohms of resistance. The magneto-generator is of exceptional importance and of great advantage in telephone service. It is of a

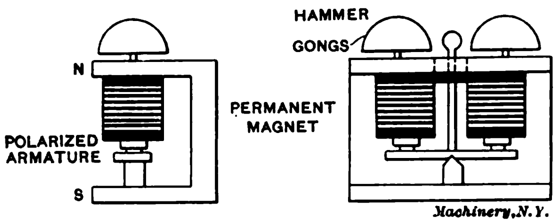

Fig. 24. Principle of Construction of the Call-bell

simple and cheap construction, it is always ready to produce an alternating current by a few turns of the handle, and is able to ring through high resistance with comparative ease. At exchange stations it is a common practice to use a magneto-generator driven by power. In some cases current for ringing purposes is supplied by an ordinary generator.

A diagrammatical view of the construction of the call-bell is shown in Fig. 24. The armature and cores are so situated in respect to each other that when an alternating current passes through the coils of the magnets, the armature is alternatingly attracted and repelled rapidly; the bell hammer then strikes the two small gongs violently. The attractions and repulsions are the results of a permanent magnet being utilized to act both as a support for the magnet cores and as a pivot for the armature. The two cores are thus magnetized by one pole and the swinging armature by the other. It is obvious that an alternating current passing through the windings of the magnets will alternately weaken or strengthen their polarities, so as to cause the armature to oscillate rapidly between the poles and thus ring the bells by the hammer attached to it.

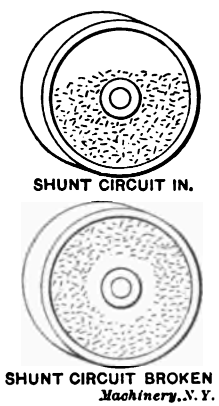

Fig. 25. Means used for Producing a Shunt Circuit

If the current entering the subscriber's call-bell from a distance had to traverse the winding of the magneto-armature it would be weakened to a point that would probably render it useless for ringing the bell. To avoid this difficulty, a shunt or side path for the current is supplied in cases where a hand-operated magneto is used for signalling. This shunt in its simplest form consists of a round box-like device attached to the shaft as shown in Fig. 25. It is partly filled with small pieces of metal which are normally at rest as shown in the upper

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view, thus providing a path for the incoming current which cuts out the magneto. When the magneto handle is turned, however, the small metal pieces fly away through centrifugal force and thus break the shunt circuit otherwise formed by their being at rest and providing a contact with the shaft. When they are at rest the armature is, so to speak, short-circuited by them, but when they are thrown against the side of the box the magneto is restored to its normal condition and may be used for signalling.

The Switch-hook

One device which is part of the telephone apparatus remains to be described. The device representing the connecting link between the two important parts of the telephone system, namely the speaking and signalling circuits, is called the switch-hook, or, sometimes, the hook-switch. It is an automatic device by means of which the receiver, when in use, cuts out the signalling circuits, and when not in use, by resting on the hook, throws them into circuit again. The principle of action is shown in Figs. 27 and 28. When the weight of the receiver is placed on the switch, it is pulled downward so that

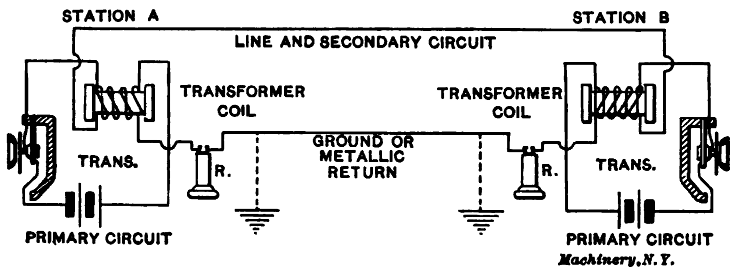

Fig. 26. Simple Two-station Telephone System

the speaking circuit composed of the battery, transformer and primary of the induction coil is cut out. When the receiver is removed, the switch-hook cuts out the circuit containing the magneto and call-bell, and produces contact with the remainder of the apparatus.

Simple Two-station Telephone System

In Fig. 26 is shown a simple two-station telephone system. In the illustration the line is shown as consisting of two metallic wires drawn with full lines, but the dotted lines indicate the possibility of grounding the ends of the circuit at each station so as to transmit the current over only one metallic circuit. The battery circuits at each end are local and operate independently of each other, and have no direct connection with the line. The battery must receive attention if its strength diminishes.

Complete Telephone Systems

Summarizing, it will now be understood that a complete telephone system consists of three distinct parts, a calling apparatus, a transmitting apparatus, and a receiving apparatus, each of these having a

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complete electric circuit. The calling apparatus consists of the magneto-generator and the call-bell, the transmitting apparatus consists of the transmitter, the batteries and the primary winding of the induction coil, while the receiving apparatus and circuit consists of the secondary of the induction coil, the line and the receiver.

Distinction is made between two types of telephones, differing as to the details of the connections between these various fundamental constituents, the two types being known as the series telephone and the bridged telephone. A diagrammatical sketch showing the connections of a series telephone is shown in Fig. 27, and of the bridged telephone system in Fig. 28.

Series Telephone System

In the illustration Fig. 27, when the receiver is placed on the hook *A*, the switch is in the position shown, the magneto-generator *B* and the call-bell *C* being connected in series with the line through the contact at *D*. The magneto-generator is automatically cut out by the method just described. If the receiver is now removed from the hook, then, due to the action of a spring, the left-hand end moves upward and the right-hand end moves down, and the contact at *D* is broken, while a contact is made at *E* and *F*. The primary circuit containing the battery and transmitter is then closed, and the secondary circuit containing the receiver and the induction coil is connected to the line, *G* and *H* being the line terminals. This type of telephone is used only where not more than two telephones are connected on a line.

The reason why the series telephone cannot be used if several telephones are connected on a line is that with series telephones ringers of from about 80 to 120 ohms resistance are used, and on account of this comparatively low resistance, it would be impossible to ring a number of the call-bells in multiple. In addition, since all the bells would be constantly in the circuit, it would interfere with the use of the instruments.

Bridged Telephone System

In Fig. 28 the call-bell is permanently bridged across the line, and the magneto-generator is also bridged, the circuit through it being open when it is not in use, and automatically closed when operated, as already described. In this system, when the receiver is lifted from its hook, a contact is produced at *A* and *B* for the primary and secondary circuits, the same as in the series telephone. The advantage of this system, however, is that the call-bell does not interfere with the action of the receiving circuit, since in this case the call-bells have a resistance of about 1600 ohms, and are wound so that their self-induction is large. With this system several telephones can be bridged upon one circuit.

Three methods are in use for constructing lines, these being the ground circuit, the metallic circuit, and the common return. In the grounded circuit but one wire is used, the other terminals being connected to the ground. In the metallic circuit two wires are used, one

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for the incoming current and one for the return. In the common return, the circuit is completed through a common copper wire, thus differentiating it from the metallic circuit where each separate circuit has a return of its own.

The telephone systems in vogue may also be classified in three general divisions, as follows:

1. The party line and intercommunicating system.
2. The central station, or central exchange system.
3. The automatic central station system, or automatic exchange.

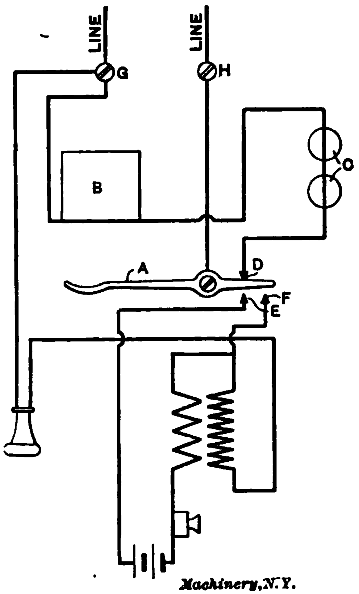

Fig. 27. Series Telephone System

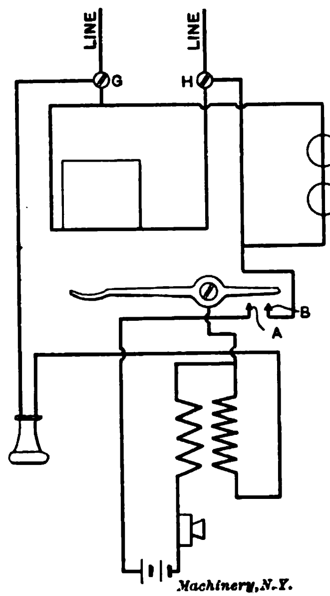

Fig. 28. Bridged Telephone System

The intercommunicating system is of great service where the number of telephones is not too great. It finds its best application in hotels, factories and houses employing many telephones. By this system of telephoning, any one in the system may be reached and spoken to readily, this object being generally accomplished by means of a specially constructed switch. The party line or common circuit system is open to objections, among which the chief one might be regarded as lack of privacy. The central station system is by far the most important.

The Central Station and Its Switchboard

Where more than 20 or 30 subscribers are dependent upon a telephone system for business or social purposes, any other than a system employing a switchboard is out of the question. In detail it consists of an apparatus so equipped that tw) subscribers may be readily placed in communication with each other when one "rings up" and

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asks for the other. This apparently simple requirement is accomplished by means of a switchboard, whose devices are adapted to this purpose, and whose functions may be classified under the following heads:

1. For notifying "central": Drops are employed.
2. For connecting subscribers: Spring jacks are used.
3. For line terminals of subscribers: Plugs with flexible cords are used.
4. For listening and ringing up subscribers: Keys or switches are used.

The switchboard is so constructed that the operator or "central" can readily see and manipulate at the same time. The drops occupy the upper portion of the switchboard, as indicated in the diagrammatical sketch, Fig. 29, and may run up in numbers corresponding to the number of subscribers' wires. Beneath these drops are the spring jacks, then on the horizontal portion of the switchboard are the plugs and keys, as indicated.

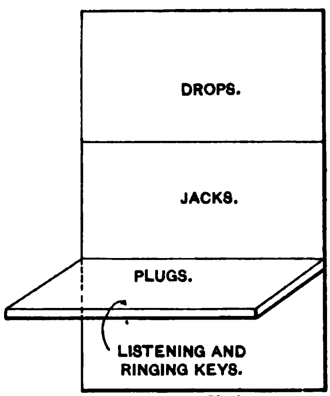

Fig. 29. General Arrangement of Switchboard

The switchboards in use for city subscribers are necessarily very large and complicated. The smaller type of switchboard, serviceable for 50, 100, 200 or 300 subscribers, would not be satisfactory to cope with a system having subscribers running into the thousands. Confusion and consequent delay would be the certain cause of failure. The operators are therefore given a certain number of subscribers apiece to take care of, with the means as well, in the switchboard construction, of connecting them to any other subscriber who is attached to the same board. Thus the labor is subdivided without any resulting delay or confusion, and each operator only takes care of 100 or 200 subscribers.

Now, when a number of small switchboards were employed, and an operator with such a switchboard desired to connect a subscriber to another on a switchboard at the other end of the room, difficulty would naturally result if no special means were provided for this contingency. To obviate this the subscribers are grouped into sections, and their lines brought to one large multiple switchboard, in which not only are the subscribers' lines in each section of easy access to the operator, but the connection permits the operators to connect the subscribers of the section in their individual charge to any other on the switchboard. This arrangement is shown in principle in Fig. 30, where the employment of local jacks simplifies the proposition. Here the jacks of all subscribers on the multiple board are found in each section of the board. Each operator can therefore connect a sub-

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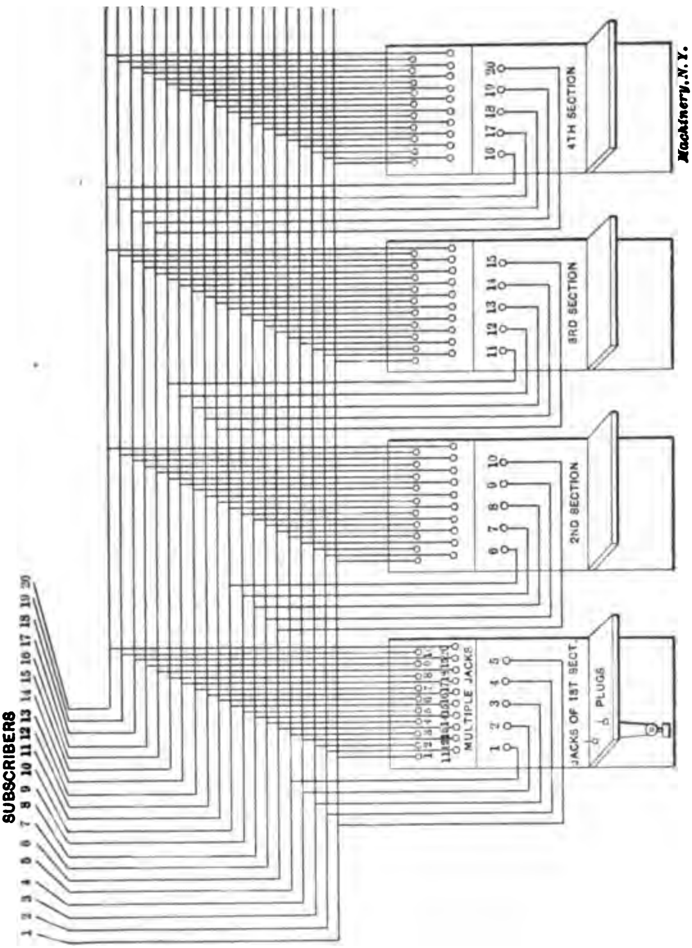

Fig. 30. Arrangement of a Multiple Switchboard

scriber with the utmost readiness with whosoever they may desire. In a multiple board, consisting of four sections of five subscribers each, if the operator in charge of section No. 1 ranges from 1 to 5, and No. 2 from 6 to 10, then they can manipulate as follows:

Operator No. 1 from 1 to 5, and to any one from 1 to 20.

Operator No. 2 from 6 to 10, and to any one from 1 to 20.

Operator No. 3 from 11 to 15, and to any one from 1 to 20.

Operator No. 4 from 16 to 20, and to any one from 1 to 20.

A study of the diagram will show the meaning of this important principle in multiple switchboards.

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CHAPTER IV

WIRELESS TELEPHONY

The name of wireless telephony is given to that system for the transmission of intelligence in which the human voice is transmitted, without a visible conductor, by means of electrical or ether waves, which are again transformed into audible speech. The waves are produced at one point, radiated, and received at another point. The electrical waves are noiseless, because they do not in any way affect the ear drum; but they can be transformed into air vibrations by means of suitable apparatus, and thus audible and intelligent speech be created, corresponding to the sounds that have produced certain conditions of the waves at the transmitting end.

The history of the invention of wireless telephony is one of the most interesting chapters in the history of invention. More than twenty years ago it was demonstrated that it was possible to transmit the sound of the voice by means of a flickering beam of light controlled by the sound waves of the human voice. But this method did not, of course, permit of the transmission of messages over very great distances, and the principle of wireless telephony as applied to-day is entirely different. The origin of the present method of wireless telephony may be traced back to the arc-light method employed by Elihu Thomson for producing a very rapid series of electrical impulses. By this means Prof. Fessenden was able in 1902 to transmit speech without the means of transmitting wires.

The progress from that time up to the present moment has been rapid. In 1906 Fessenden was able with an apparatus reasonably simple, considering the object to be secured, to transmit speech over a distance of eleven miles. Later he has been using an alternating current dynamo having a frequency of from 50,000 to 80,000 cycles per second. With this machine as the source of electrical waves, wireless telephony has become possible over distances of several hundred miles. In this connection the experiments of Prof. Poulsen, a Danish inventor, should be mentioned. He has achieved considerable success along the lines of wireless telephony. Other inventors which may be mentioned are Majorana, of Italy, and De Forest, an American.

High-frequency Waves Used in Wireless Telephony

The primary requirement in wireless telephony is to produce electric waves having a very high frequency, that is, moving through space at very short intervals. The simplest method by means of which waves can be produced is by means of an alternating current dynamo so constructed that it creates 100,000 alternations per second, more or less. This wave action may be considered as a kind of background on which the specific waves, due to the sound, are impressed. This background

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is called the wave train. There are three methods of producing electric waves or wave trains of high frequency. They are as follows:

1.—The spark-break method, in which a circuit containing capacity, inductance and resistance is used for producing a series of sparks and consequent waves. Any circuit consisting of a condenser, resistance and induction coils and supplied with electrical energy at high pressure will produce electric waves by this method. It is, however, not considered a practical method for wireless telephony.

2.—An alternating current generator or some equivalent device, capable of producing 20,000, 50,000 or 100,000 cycles per second.

3.—The arc light as modified by capacity and inductance by Elihu Thomson in 1893, and W. Duddell in 1900. The latter discovered the properties of the so-called singing arc, produced by shunting a circuit having a condenser and inductance in it, as indicated at *B* and *C*, Fig. 31. High frequencies can be obtained in this manner at an estimated rate of 300,000 to 3,000,000 per second.

Each of these methods requires consideration in the construction of a practical wireless system. The main point to remember, however, is that there are two sets of waves utilized, one called the wave train, and produced by the means just mentioned, and a second set of waves that is impressed upon the wave train by the voice or sound waves to be transmitted.

Comparison Between Methods Used for Producing High Frequency

In the alternator used for producing a high frequency it is necessary to use from 200 to 300 magnetic poles on the machine, and the armature must be revolved at a very high rate of speed. The number of alternations of the current is directly depending upon the number of poles and the number of revolutions per minute, the number of alternations being the product of these two latter numbers. The difficulties of the method are, first, that the revolutions per minute of the armature are limited by the strength of the moving parts, as these would burst, due to the centrifugal force, if revolved at too high a rate of speed, and, second, that the magnetic poles must be placed very close together, which is unsatisfactory from an electrical point of view. On account of this, and also on account of the expense of machines of this type, the singing-arc method has been employed for producing the waves required.

In this method two solid conductors are used, one of carbon and one of copper, with a short gap filled with air or other gas between the conductors, as shown at *A*, Fig. 31. The electric resistance of the air gap varies the strength of current flowing through it, and on this depends the principle of the device. When cold, the resistance of the air space is very great, but when heated by the flow of the current across it, the resistance falls to a very low value, and a very small variation in the strength of the current will cause a corresponding change in the resistance opposing it in the space between the electrodes. The ends of the electrodes are connected to a system of conductors which determines the frequency of the electrical vibrations.

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The action is in main as follows: When a direct current from a dynamo or a battery is sent through the air gap *A* as shown in Fig. 31, the electricity in the circuit attached to it commences to alternate at a rate controlled mainly by the condenser and resistance shown at *B* and *C*. Hence, we have here a simple method of obtaining alternating currents of high frequency by a direct current. In order that the variations of the resistance at *A* may be as sensitive as possible, it is important that the electrodes are cooled rapidly. In some devices the copper electrode is cooled by air or water, by means of special devices.

Conditions Governing the Use of an Arc

The conditions that must be established in the use of an arc are, according to Mr. Duddell, as follows:

1.—The arc must be supplied with a steady electromotive force, obtained from storage or primary cells, if a generator is not convenient.

2.—Solid carbons instead of cored must be employed.

3.—The induction coil employed must be of low resistance.

4.—The condenser must be constructed to stand high pressure without a breakdown, and also sudden variations in the amount of the charge.

By producing the arc in hydrogen gas or illuminating gas the waves thrown out per second are increased in number. An arc burning in air will produce 50,000 waves or alternations per second, while an arc burning in hydrogen will produce over 300,000 waves per second. The length of the arc is an item of considerable importance, as it bears upon the success or failure of the system. Too long an arc will not work, nor will too short an arc. There is a given length called the active length of the arc which must be adhered to in operating the system. If, when the arc is active, the waves become too rapid, then the arc must be shortened.

The Wireless Telephone System

It will now be understood that a wireless telephone system divides itself into three distinct parts, as follows:

1.—The apparatus producing the wave train.

2.—The apparatus used for transforming the voice vibrations into electrical waves impressed upon the wave train.

3.—The apparatus used for receiving the electrical wave equivalent of the voice and transforming it into speech.

The parts of the transmitting station (see Fig. 31) are as follows:

The microphone transmitter circuit.

The arc lamp or wave-producing circuit.

The radiation or antenna circuit.

This indicates that the telephone transmitter is spoken into, which impresses this set of vibrations on the wave-producing circuit and by means of the antenna radiates the same into space.

The parts of the receiving station are as follows:

The telephone receiver circuit.

The wave detector.

The aerial and tuning circuit.

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The Transmitting Apparatus

In Fig. 31 is shown the transmitter or sending apparatus. At *E* is shown the transmitter of similar kind as the ordinary telephone transmitter, and connected in the local circuit containing a battery and the coils of a transformer, the battery being shown at *F*, and the transformer at *D*. By means of the transformer *D* the current in the local circuit passing through the transmitter controls the supply of current to the arc at *A*. At *B* is shown a condenser, and at *C* a coil of wire giving inductance as already mentioned. At *G* is a second transformer by means of which the generating circuit through *A*, *B* and *C* is con-

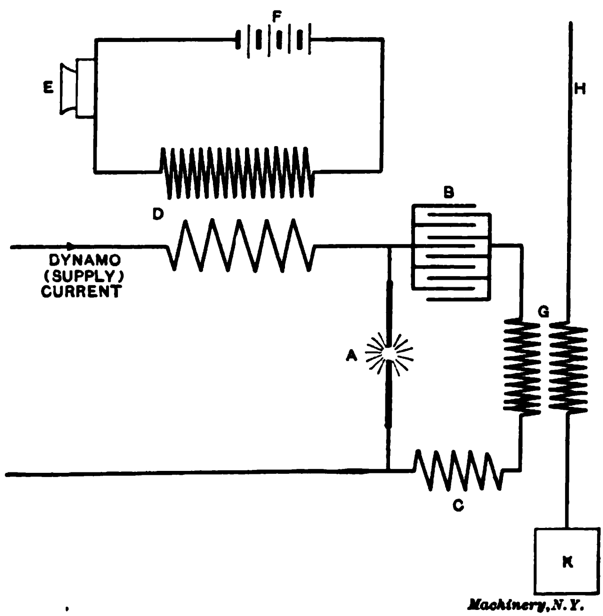

Fig. 31. Transmitter or Sending Apparatus

nected to the antenna *H* and the ground connection *K*. By this means the electric waves, as produced by the speaker's voice, are transmitted into space. The transmitter current of the local circuit influences by induction the supply current so that this current is increased or decreased in a manner corresponding to the sound waves impinged upon the diaphragm of the transmitter.

Several forms of aerial conductors, by means of which the current passes out from the instruments, have been devised. The best one is undoubtedly the fan-shaped aerial or antenna. The lower end of the aerial wire is led into the instrument room and there connected to one terminal of the current generating coil, while the other terminal is connected to a large metal plate sunk into the ground as shown at *K* in Fig. 31.

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The current is actually conducted by the earth, so that the electrical resistance of the ground influences to a considerable extent the possibilities of wireless transmission. The resistance in the sea being low, the possible distance of transmission of wireless messages over water is much greater than over land, and it is also easier to transmit messages over moist soil than over dry soil. It has been found that the differences are very considerable, and that a station which can transmit speech over a distance of say fifty miles over dry land can transmit with equal ease the speech over 200 miles of water. It has also

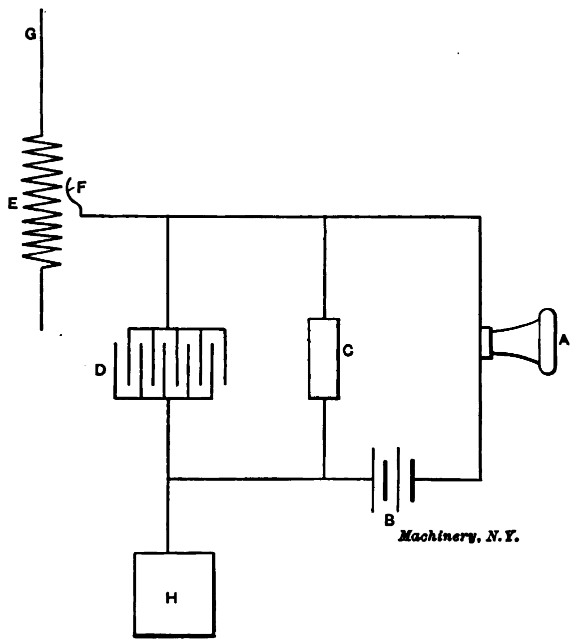

Fig. 32. Diagram of Receiving Apparatus

been found that conditions in the atmosphere account for curious differences in transmission by day and night. This was first discovered by Marconi.

Receiving Instruments

At the receiving end of a wireless telephone system there is an aerial conductor and earth connection similar to those at the sending station. In this case, however, the aerial conductor is connected to the receiving instrument the same as is also the ground connection. In practice, of course, there is a receiving instrument and a sending instrument at each end of the line, either of which can be connected to the aerial and ground connections, so that speech can be transmitted and received at each station.

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A receiving apparatus is shown diagrammatically in Fig. 32. At *A* is shown the receiver, and at *B* a battery for producing the local current actuating the receiver. At *C* is shown a detector by means of which the local circuit is connected when the detector is impinged upon by the electric waves transmitted. At *D* is a condenser, and at *E* a coil with a sliding connection *F* which is used for "tuning" the circuit *G E D H* to the frequency of the transmitted current. *G* is the aerial conductor, and *H* is the earth connection.

In the receiving apparatus the alternating current of high frequency transmitted through the ether is transformed into a direct current, the strength of which is proportional to the average value of the alternating current. The direct current is then transformed into air vibrations and sound by means of the ordinary telephone receiver. The so-called tuning of the instrument permits of working several wireless stations at once within the same area of electric influence without interference. The object in view is accomplished by the arrangement of the stations in pairs, each of which works with a current having a different number of alternations per second than the other pairs. In a case of that kind each receiver will interpret such messages as are sent by its corresponding station, ignoring all others. The system, of course, is so arranged that the receiving apparatus can be quickly changed so that any one station can communicate with any other by tuning the instruments to correspond.

The detector employed in wireless telephony may be either of electrolytic or silicon type, or of any convenient form suitable to the purpose. Detectors may be generally classified as of the coherer type, the silicon type, the thermal, or the electrolytic type.

The coherer type consists of a tube of nickel and silver filings sensitive to the impact of ether waves of high or low frequency.

The silicon type consists merely of a piece of silicon in the detecting circuit, which is affected by and extremely sensitive to the ether waves.

In the thermal type, Prof. Fessenden uses a fine platinum wire 0.00006 inch in diameter to detect waves by their thermal effect. In the Collins system a thermo-detector is used for the waves, consisting of two wires mounted and crossing each other. They are of different metals and act most satisfactorily. The inventor claims a sensitiveness which detects and acts with power equal to 0.00002 of an erg.

The electrolytic type consists of a platinum wire dipped in vitric acid, sensitive to the ether waves by the variations in resistance due to the minute electro-chemical changes on the surface of the platinum wire.

General Considerations

There is an interesting law governing the amount of radiation from a wave producer. This law may be stated as follows: Radiation increases with the fourth power of the frequency. The table below indicates this relationship:

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TABLE OF RADIATION

Distance	Frequency, or Waves per second	Radiation from Antennae
1	10,000	1
4	20,000	16
16	40,000	256
64	80,000	4096

In explanation of the table given it may be said that the range or mileage of an apparatus varies with the square root of the intensity of radiation; that is, as shown in the table, if the frequency per second is doubled, the radiation increases by the fourth power and the distance by the square. For example, when the frequency is doubled the radiation becomes sixteen times as great and the distance over which the influence is felt becomes four times as great.

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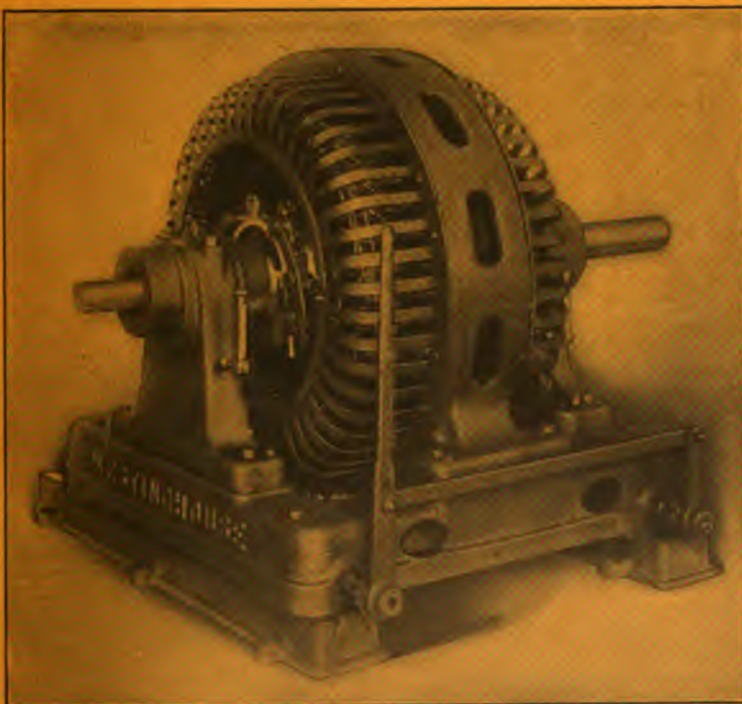

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PART VI

TRANSMISSION OF POWER

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CHAPTER I

GENERAL PRINCIPLES OF POWER TRANSMISSION

The term "power transmission" is self-explanatory, referring as it does to the transmission of power, *i. e.*, the development of power at one point and its delivery at some other point more or less distant. There are, however, a number of other expressions which are used in connection with the subject of power transmission and which are not as easily defined, and it is therefore deemed advisable to define such words as force, energy, work, power, efficiency, etc., before dealing specifically with the subject of power transmission by means of electricity.

According to Newton's definition, a force is any cause which tends to move a body from a condition of rest to motion, or from a condition of motion to rest. According to a more modern definition, force is any cause that produces, stops, changes, or tends to produce, stop or change the motion of a body. There are two classes of forces: those which act upon a body from without, and those which act upon a body from within. The first class may be termed external forces, and the second class molecular forces.

When motion is produced by a force against a resistance, work is done. In the popular conception of the meaning of the word "work," a visible result is usually presupposed. In a mechanical sense, however, work is supposed to have been performed whenever certain forces have been active against a resistance. The work, for example, may consist of lifting a body against the resistance of gravity, or of moving a body along a horizontal plane against the resistance of friction; but work is also done if simply the friction within a mechanism is overcome, without any other useful result having been accomplished. Work is commonly measured in foot-pounds. A foot-pound is the amount of work done in lifting one pound a distance of one foot against the force of gravity. According to the metric system, in which the kilogram, a weight equal to 2.2 pounds, and the meter, a distance of 3.28 feet, are the units of weight and length, respectively, a kilogram-meter is the unit of work.

Energy is defined as the power or capacity of doing work, and may be classified as kinetic and potential. Kinetic energy is due to motion, while potential energy is due to the position or inherent condition of a body. A moving body which overcomes resistance displays kinetic energy. The amount of energy it displays depends upon its speed of motion, or velocity, and the resistance to its motion. The potential energy of a body resides in it irrespective of motion, and may be defined as its capacity or possibility for doing work. For example, a body of water at a high elevation enclosed by a dam is not performing

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work, but it is possessed of potential energy, because it has the possibility or capacity for doing work if released and permitted to fall, under the action of gravity, and to operate some hydraulic machinery during the motion thus resulting. Potential energy is also present in a body thrown in the air at the instant before it commences to fall again. In this latter case the potential energy is rapidly transformed into kinetic energy when the body commences to move downward. It may also be said that potential energy is present in gun-powder and dynamite, because these substances possess a capacity for doing work, although that work is not being performed until, due to certain circumstances, such chemical action takes place which permits the potential energy to change into kinetic energy.

A machine, strictly speaking, should be defined as a device by means of which a force is able to produce an effect or do work. In a majority of cases it is supposed that the machine is doing useful work, that is, work which can be utilized for producing desired effects, although this is not always the case. The whole output of the work of a machine, for example, may be sometimes absorbed by friction, and thus apparently lost, as far as its usefulness for accomplishing a desired effect is concerned. The force applied to a machine is commonly called the power.

A distinction is sometimes made between a machine and a motor. A motor is in some instances regarded as the source of power in a purely mechanical sense; in other words, a motor is a machine which transforms some form of energy into mechanical motion. A broad application of the word energy is here made use of, according to which electricity is a form of energy, and the expanding quality of steam or the explosive possibilities of gas are other forms of it. The machines by means of which the energy of electricity, steam or gas can be transformed so that their respective powers can be utilized for doing useful work are very different from each other; but while the machines and the methods of transformation differ, the mechanical results are alike.

As already stated, a force applied to a machine is commonly called the power. The expression "power" is also used for expressing the amount of work that is being done in a certain period of time. A horsepower, for instance, expresses the rate of work done per minute or per second. It is equal to 33,000 foot-pounds per minute. This means that in order to lift, for example, 1,000 pounds 33 feet in one minute, work to the amount of 33,000 foot-pounds, or one horsepower, must be done in one minute. The element of time must be considered, otherwise the rate at which the work is being done cannot be estimated. The time need not necessarily be a minute. It may be a second, in which case only 1/60 of the power would be required; 33,000 foot-pounds a minute, hence, equals 550 foot-pounds per second. The power, however, is still equal to one horsepower.

The power of steam engines, gas engines or electric motors is rated according to this basis. They are built to produce power at a certain rate per second, or per minute. Commonly the electric motor is rated by the second, while the steam engine is rated by the minute,

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but if a properly constructed one horsepower electric motor and a one horsepower steam engine are compared with each other, at normal nominal load, it will be found that each produces 33,000 foot-pounds per minute or 550 foot-pounds per second. The voltage and current required for the electrical machine, and the quantity of steam and its pressure required for the steam engine, must vary to produce the different amounts of power, but in both cases, one kind of energy is transformed into another. In the first case the electricity is transformed into magnetism through which a pulling action is developed between the field magnets and the armature of the motor, causing rotation, as indicated in Fig. 1. In the second case steam is expanded in the cylinder of the engine, as indicated in Fig. 2, and while thus expanding, forces the piston forward, and transmits power through the piston-rod and connecting-rod to the crank-shaft. In both cases the power produced can be taken off by belting or other means, so that in both cases the results are the same, although the means employed for producing the results are different.

The efficiency of a device or machine may be expressed as the ratio between the power taken out of the machine and the power sent into

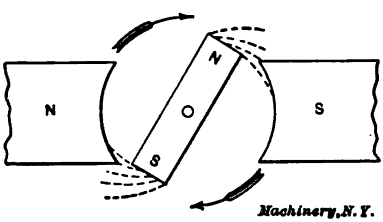

Fig. 1. Principle of Action of an Electric Motor

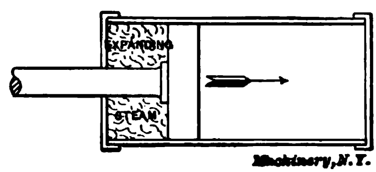

Fig. 2. Principle of Action of a Steam Engine

the machine. For instance, if an electric motor develops 8 horsepower, that is, if 8 horsepower can be taken off from the belt pulley of the motor and used for driving other machinery, and an amount of electrical energy equal to 10 horsepower has been sent into the motor in the form of electric current, to produce the motion of the motor, then the efficiency would be the ratio of 8 to 10, which equals 0.8 or 80 per cent. In power transmission of whatever kind, whether electrical or purely mechanical, the efficiency is one of the most important features to be considered. The choice of method for power transmission is usually guided entirely by the efficiency expected, and the cost of the various apparatus required.

Methods of Transmitting Power

Although it may be stated as a demonstrated fact that electrical transmission of energy is by far the most efficient method in existence when all factors are taken into consideration, other methods have been tried extensively, and are used to a considerable extent under favorable conditions. Power may be transmitted for certain distances by means of steam, compressed air, water, and wire rope. In large cities, notably

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in New York, steam pipes extend over considerable distances under the streets of the city. While the steam is used mainly for heating and its utilization for power is very limited in comparison, it may be conceived of that steam for power purposes might be transmitted over small areas in this manner. In Paris a system of pipes carrying compressed air met with general success for some time; in the same way water under pressure can be readily converted into power by means of small water wheels. But these systems cannot be employed for the transmission of power between points widely apart. They represent a case of the distribution of power over short areas.

Wire rope transmission belongs to a class of its own, yet it exemplifies the principle of transmitting power from point to point. A wire rope moving over a distance of several miles cannot, however, be very efficient. The friction, inertia and repairs are very great. It has been estimated that the cable power transmission used for the street car systems some years ago in New York and Chicago barely reached the figure of 20 per cent efficiency; that is, out of over 1,000 horsepower developed, only 200 horsepower were effective in moving the street cars. Hence wire rope transmission is very inefficient, even over comparatively short distances. Over long distances, such as 10 miles or more, the wire rope, compressed air, water or steam methods of power transmission would practically prove commercial as well as engineering failures. Power transmission over long distances is exclusively carried out by means of electricity.

Electric Power Transmission

The transmission of a high-tension direct-current over lines of considerable length is attended with difficulties which present almost unsurmountable objections to its use. The alternating current, instead, seems to be particularly adapted to long distance power transmission. The reasons why the direct-current cannot be employed are, in the first place, cost and difficulty of insulation, and second, the difficulty of transformation. On the other hand, when an alternating current is employed for long distance transmission, the insulation problem is comparatively easy; there is no necessity for revolving parts in the transformers; and the transformation from a high to a low potential or voltage, and *vice versa*, and from an alternating to a direct-current is readily, cheaply and efficiently accomplished. The cost of installation is also much less with alternating current generators than with direct-current generators.

The alternating current employed for long distance power transmission is as a rule not the ordinary single-phase current, but the two- or three-phase current. A two or three-phase current is employed because it makes a properly constructed motor self-starting, which is a condition impossible to accomplish with a single-phase current. The self-starting feature is also of importance when at the end of the transmission line it is desired to change or transform the alternating current into direct-current by means of a rotary converter. These various subjects will be treated more in detail in subsequent chapters.

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Efficiency of Transmission

Whether direct or alternating current is employed, the efficiency of the system, that is, the percentage of power returned out of the total power sent into the line, is of the greatest importance. There are a number of considerations which must be taken into account, when the problem of transmitting a given power over a given distance is to be solved. The most important features of the problem are the drop of voltage in the line, the power lost during transmission in the line, the cost of the copper wire employed, and the relation between the cost of the copper and the power lost during transmission.

In order to examine a specific case, let us assume that 100 horsepower are to be transmitted a distance of one mile with a 10 per cent drop in voltage. If the engine delivers 100 brake horsepower and the dynamo transforms, say, 95 per cent of this power into electrical energy, then 95 horsepower will enter the transmission line. Assume that of this 90 per cent will be delivered at the other end of the line. The power delivered then at the distant end of the line will be 95 — 9.5 horsepower, leaving a balance of 85.5 horsepower. The process, however, is not yet completed, although the power is now at hand, ready for use. It is now necessary to transform it again into mechanical energy by means of an electric motor. This transformation involves a loss of from 5 to 10 per cent on an average. Hence the balance left will be 85.5 — 8.55 = 76.95 horsepower with 10 per cent loss in the motor, and 85.5 — 4.275 = 81.225 horsepower at 5 per cent loss in the motor. The efficiency of transmission with a 100 horsepower at the one end, and with the losses throughout in the dynamo, transmission line, and motor taken into account, will thus be about 77 per cent with a 10 per cent loss in the motor. The 100 brake horsepower delivered by the engine is thus reduced to 77 horsepower on account of the electric transmission. This loss is not prohibitive if the cost of the transmission line is within reasonable limits. In some cases, however, the cost of the transmission line becomes very high, sometimes prohibitive, and in such instances certain means must be employed to raise the efficiency or to reduce the cost of installation. It is evident that a high efficiency is profitable or not, according to whether the increased cost of installation, due to the increased efficiency, is proportionately less or greater than the gain in efficiency.

Effect of High Voltage on the Efficiency

When power is lost in the transmission line it is wasted in the form of heat. This loss is commonly called the C^2R loss, and is due to the dissipation of the electrical energy through the resistance. The reason why this loss is termed the C^2R loss is because it equals the square of the current, in amperes, multiplied by the resistance, in ohms. The product obtained is the heat loss in watts. This loss is of a serious character and increases rapidly with any increase of current in the circuit. The relationship between the power loss in the transmission line to the strength of current, in amperes, in the line, is shown in Table I. The figures in this table illustrate the influence of a diminish-

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ing current and an increasing resistance upon the losses in the line. The current is shown to diminish systematically, while the voltage increases in the same proportion, so that the total amount of power transmitted is kept constant. The loss of power in heat during the transmission, however, is shown to diminish with a decreasing strength of current, even when the resistance increases. It is thus evident that the losses in transmission are due to the use of a heavy current. One of the axioms, therefore, of electric power transmission is that the current should be kept at a minimum value by the employment of high voltages in the transmission line. As will be seen in Table I, in the first line of figures given, the total drop with 10 ohms resistance and a current of 10 amperes is 100 volts. A loss of 100 volts out of 1,000 is a drop of 10 per cent and at the same time a resistance of 10 ohms causes a waste of 1,000 watts of the total power of 10,000 watts sent through the line. This is a loss of 10 per cent of the total power to be transmitted.

Now suppose a power line one mile in length is to be erected whose total resistance is one ohm. If 10 kilowatts (10,000 watts) are to be

TABLE I. LOSS IN HEAT IN POWER TRANSMISSION

Amperes	Volts	Resistance in Ohms	Total Drop in Volts	Loss in Heat in Watts
10	1,000	10	100	1,000
9	1,111	11	99	891
8	1,250	12	96	768
7	1,428	13	91	637
6	1,667	14	84	504
5	2,000	15	75	375
4	2,500	16	64	256
3	3,333	17	51	153
2	5.000	18	36	72
1	10,000	19	19	19

transmitted at a voltage which is chosen so as to obtain the most economical results, then the following considerations must be observed: the effect of an increasing pressure—the total amount of power remaining the same and the resistance of the line not varying—will be that of greatly improving the operation of the system. This may well manifest itself in a reduced loss in the transmission, represented both by a smaller drop in voltage and by less loss of power in heat. In the case used as an example, if a power of 10,000 watts were to be transmitted at a pressure of 100 volts, a current of 100 amperes would be required. If the resistance in the line is one ohm, it will be seen that the total energy to be transmitted would be wasted in heat, the waste in heat being equal to the square of the current, in amperes, multiplied by the resistance, or $100^2 \times 1 = 10{,}000$ watts dissipated in heat. This condition would be a case in which the efficiency of the transmission would be 0. A pressure of 100 volts hence would be entirely impossible for transmitting the power mentioned with the given resistance.

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Let, however, the pressure be raised to ten times this value, or to 1,000 volts, the resistance remaining at one ohm. Under these circumstances 10,000 watts would be transmitted with a current of 10 amperes. With one ohm resistance in the line, the drop in voltage would be $10 \times 1 = 10$ volts, and the loss in heat would be $10^2 \times 1 = 100$ watts, that is, the loss in heat and in voltage would be but one per cent. The increase of the voltage to ten times its original value thus had the effect of reducing the heat loss from a total equivalent of 10,000 watts, representing the waste of all the power, to 100 watts or one per cent of the power. In other words raising the pressure to 10 times its value reduced the loss to 0.01 of its value. From this we may formulate the fundamental law that if the resistance of a transmission line remains constant, and the total amount of power to be transmitted also is constant, then if the voltage is increased, the loss due to the transmission is reduced inversely as the square of the voltage. According to this, doubling or tripling the voltage, the total power and line resistance remaining constant, produces a reduction of the heat loss of 1/4 or 1/9, respectively, of its value with the original voltage.

Generating the Power

The fact that a high voltage is necessary in developing power for transmission, that it must be transformed up or down, as the case may be, and that a commutator is absolutely out of the question for voltages beyond a certain point, leads inevitably to the conclusion that the only solution to the power transmission problem is to be found in the application of an alternating current. Here again a difficulty arises of a most important character. The simple alternating current, although readily generated and transformed, is hardly suited to the purposes ultimately held in view, namely, the transformation of electrical into mechanical energy. Recourse is, therefore, as is already mentioned, had to the two-and three-phase alternating current for such purposes.

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CHAPTER II

POWER TRANSMISSION PLANT AND APPARATUS

Modern power transmission plants, consist, in general, of an equipment of two or three-phase alternators and step-up transformers, with either water power or steam as the original source of energy. The receiving or distributing end of the system consists of step-down transformers and a rotary converter. If the current is to be distributed simply as an alternating current for power purposes, no rotary converter is necessary. In Fig. 3 a diagrammatical view of a power transmission installation is shown. In the power station the engine, generator, switch-board and step-up transformer are shown. From the power station the current is carried by the line to the transforming sub-station, provided with switch-board, step-down transformer and rotary converter. We will now describe each of these apparatus in detail.

Generators

The generators used in producing alternating current are commonly termed alternators. They can be made of three types. In the first type the armature revolves and the field magnets are stationary. In the second type the field magnets revolve and the armature remains stationary. In the third type, usually called inductor alternators, both field magnets and armature are stationary and iron cores revolve between the armature core and the field magnet poles.

Every alternator is designed to work at a particular frequency. By frequency is meant the number of alternations or changes in the direction of a current in a circuit per second. For example, if a current in an alternating machine changes its direction 200 times per second, it is said to possess 200 alternations per second, or the frequency of the alternator is 200. The higher the frequency is the greater is the drop in voltage, due to inductance, but the smaller are the transformers necessary for changing the voltage from a higher to a lower one, or *vice versa*. The frequency in alternators may be as low as 20 or as high as 200 or more, according to the purpose for which the current is to be used. Arc lighting, for example, requires a frequency which is not less than 40. The numerical value of the frequency is obtained by multiplying the number of revolutions of the alternator per second by the number of pairs of poles. In practice a high frequency is obtained by using multi-polar machines, that is, machines having a great number of poles.

The unfavorable effect of a high frequency upon the capacity of a line to conduct a given amount of energy has led to the adoption of as low a frequency as is consistent with a continuity of flow. The reason why a high frequency influences the capacity of the line adversely is that

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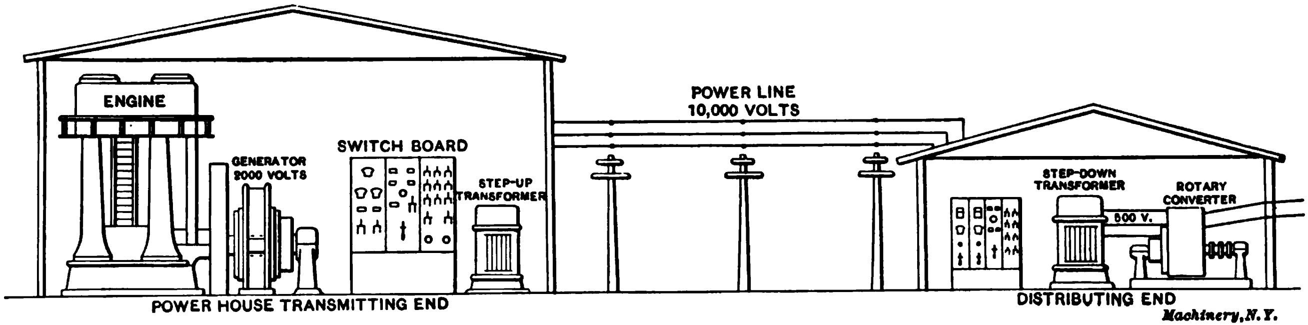

Fig. 3. General Arrangement of Power Plant and Sub-station

the question of the ohmic resistance of the line becomes secondary in circuits carrying a current of high frequency, the inductive resistance being the limiting influence in all cases where a high frequency is employed. The frequency is generally from 50 to 120 cycles per second, for electric lighting. The effect of increasing the frequency is to make the copper conductor become inoperative. The cross-section of the conductor will not be permeated by the electrical energy. It passes along the outer surface more and more as the frequency is increased, until at very high frequencies a thick copper bar becomes practically non-conductive to the electric current in this form. Low frequencies in power transmission plants are, therefore, necessary features in order to obtain efficient transmission.

General Construction of Single-phase Alternators

All dynamos or generators of electric current produce an alternating current in the coils. Hence the principle of construction of the alternating current dynamo is the same as that of the direct-current dynamo, except that in the latter a commutator is used for changing the alternating current in the armature conductors to a direct-current for the external circuit. In the alternator, a pair of collector rings are substituted for the commutator. These collector rings are connected to the armature winding, and brushes connected to the external circuit are in constant contact with the collector rings.

Alternators are generally compound-wound in order that they may give a constant potential or voltage. Instead of

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a shunt-winding such as is used on direct-current compound-wound machines, however, a small constant potential direct-current dynamo is used to supply the required current for the field magnets. This small dynamo is sometimes coupled directly to the end of the armature shaft of the alternator, but is more commonly belted to a pulley on that shaft. The series coils of the field magnets of the alternator are excited by a current obtained from the alternator armature, in manner similar to that used in direct-current dynamos, and which has been explained in Part III of this treatise, MACHINERY's Reference Series No. 75. The alternating current cannot, however, be used directly for this purpose, and, therefore, a commutator is employed which changes the alternating current into a direct-current for use in the field magnet windings. This current, while direct, is a pulsating current, that is, the potential

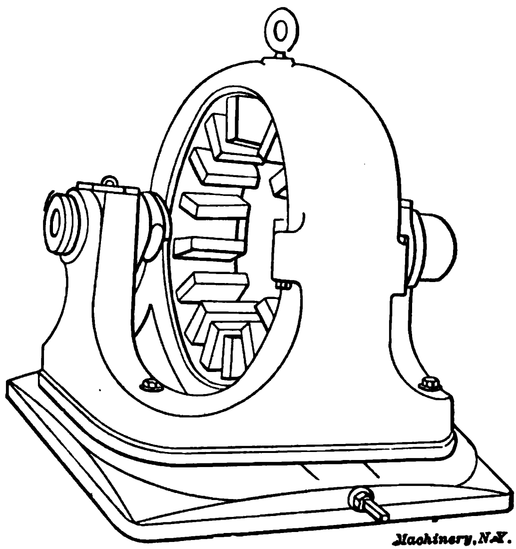

Fig. 4. Frame for a 120 K. W. Single-phase Alternator

rises from a minimum to a maximum value, and then falls again to a minimum; the action is somewhat similar to that of a pump without a pressure chamber.

The current for the series coils, rectified as described, is now led from the commutator brushes to the field coils, and this arrangement permits of a regulation of the potential of the generator. The regulation of the alternator is thus accomplished as easily as in a direct-current machine. The main energy of the fields, however, is that received from the exciter or small direct-current dynamo already mentioned; only the regulating portion of it is received from the armature itself. This flexible combination of the two methods has made single-phase alternators thus equipped very successful.

The shifting of the brushes on the commutator will be sufficient to meet and correct voltage variations. The brushes may be set when

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the voltage decreases, or when it rises, or to meet a certain condition of overload otherwise impossible to adequately control. The voltages developed by standard machines run from 1,100 to 2,200 volts, and the alternations are about 16,000 per minute. The fields are made of thin sheet steel, very soft and of high permeability. These sheet steel

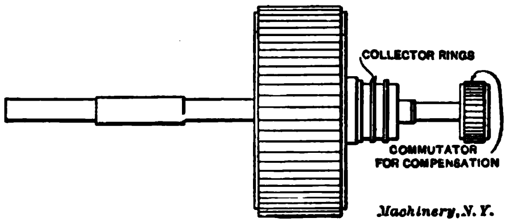

Fig. 5. Armature for 120 K. W. Single-phase Alternator

plates are held in a mold when the frame is being cast. The poles and the frame are thus incorporated with each other as shown in Fig. 4. Joints are avoided by this means and a higher efficiency and

TABLE II. DATA FOR 16,000 ALTERNATION SINGLE-PHASE ALTERNATORS

Capacity in Kilowatts	No. of Poles	Belt Speed in Feet per Minute	Weight in Pounds	Revolutions per Minute
45	10	4,607	3,280	1,600
60	12	4,542	4,180	1,335
90	14	4,488	6,480	1,145
120	16	4,450	7,970	1,000

better regulation results. The armatures of this class of alternators are slotted and receive a coil very readily, the teeth being cut with parallel sides. The windings are easily held in place by fiber wedges

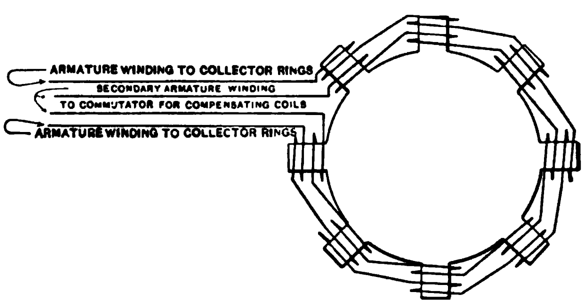

Fig. 6. Principle of Armature Winding

which are removable when examination or repairs to armature coils are necessary.

The field and armature shown in Figs. 4 and 5, are for a 120 K.W. single-phase alternator. The principle of the winding for compensa-

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tion is shown in Fig. 6. Some data relating to the capacity, speed, number of poles, etc., are given in Table II.

Engine Type Alternators

For large plants where heavy currents are transmitted or distributed at a comparatively high voltage, the flywheel of the engine and the armature cf the single-phase alternator are built in one. The *vis viva* of the armature is sufficient to perform the function of the flywheel proper, without detracting in any way from the efficiency or capacity of the plant. The armatures in this case are built up of a spider upon the rim of which the laminated iron of the armature is secured, as indicated in Fig. 7. A huge flywheel thus results, which serves as an alternator armature. This idea originated in Europe, particularly in Germany and Austria, and is satisfactory as a saver of space and expense. The coils are formed before insertion into the slots. By this means no difficult work is required to make substitutions for injured coils, and only ordinary care is necessary in assembling the armature. The principle is carried out also in a reverse manner, the poles revolving and the armature remaining stationary.

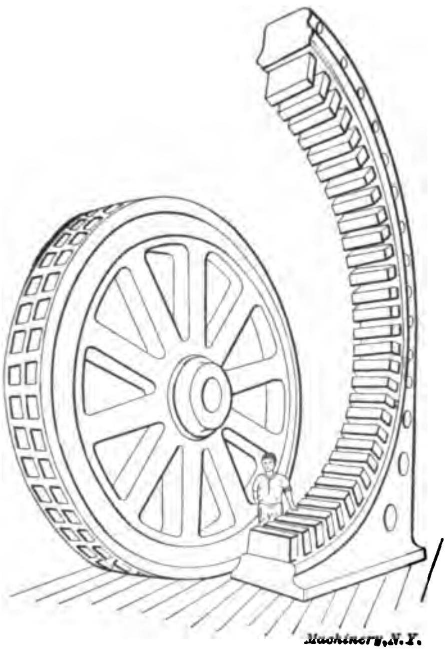

Fig. 7. An Engine-type Generator

TABLE III. DATA FOR ENGINE TYPE ALTERNATORS

Capacity in Kilowatts	Alternations	Revolutions per Minute
300	7,200	130
400	7,200	150
500	7,200	144
750	7,200	90

The gigantic size of large electrical machinery can be best understood by examining Fig. 7, showing the comparative size of an armature and field and a man. The machine in this case represents a 1,500 K.W. generator with an armature of the character described. The armature

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has not been assembled and the laminations of the armature have not been attached.

Two- and Three-phase Alternators

The type of alternator so far described is the single-phase alternator. As already mentioned, two and three-phase alternating current lends itself, in general, better to the purpose of power transmission. The meaning of the phases of alternating current has been referred to in Part III of this treatise, MACHINERY'S Reference Series No. 75. Briefly, two alternating currents which arrive at different points of their cycles, as their maximum or minimum values, or their point of reversal, at the same moment, are said to be in phase. If, however, one current reaches its maximum value a certain time previous to another current, then the two currents differ in phase. Alternators which are employed for furnishing current which thus has either two or three phases are called two or three-phase alternators, respectively. The separate phases of the current are produced by separate windings of the armature, so arranged as to produce the desired phases. In two-phase machines the difference in phase is one-quarter of a complete cycle. Each armature winding is usually provided with a separate pair of collector rings, making four rings in all. Four wires are also required for carrying the current. Sometimes only three collector rings are used, in which case only three wires are used in the line. In this case one ring is used for each of the armature windings, while the third is common to both. The line wire connected to this common collector ring carries at any moment a current equal to the sum of the currents in the other two wires at that moment.

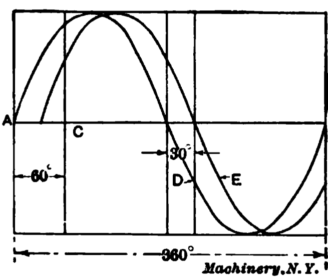

Fig. 8. Graphical Method of Representing Electromotive Force

In the three-phase alternator three distinct windings are used, the difference in phase being one-third of a complete cycle or alternation of the current. In this case the current flowing in one direction is at any instant equal to the current flowing in the opposite direction, so that only three wires are required for the three separate currents. At any moment one of the wires will act as the return conductor for the other two. Only three collector rings are required as well.

When dealing with alternating currents, the graphical method of representing the electromotive force or current, as shown in Fig. 8, is very convenient, as it illustrates to the eye the rise and fall of the electromotive force and the pulsations of the current. As a rule, only one period or cycle is drawn on the diagram, all the cycles being alike. The length of one cycle, as from *A* to *B* is assumed to equal 360 degrees, irrespective of the length of time required for the complete cycle. This method makes it possible to designate different points on the curve as being a certain number of degrees apart. For example, in Fig. 8, if the line *AB* is assumed to be 360 degrees, then the distance from

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A to *C* being 1/6 of the total length, *AC* would be 60 degrees. This method of designating various curve points makes it possible to speak of the angle between two curves drawn in the same diagram; for example, the angle between the curve designated as *D* and the curve designated as *E*, would be 30 degrees.

Power Factor

If an alternating electromotive force is applied to a circuit the resulting alternating current may or may not have its changes in direction occuring at the same time as the alternating electromotive force. If the changes of the current take place exactly at the same time as the changes in electromotive force, then the two are said to be in the same

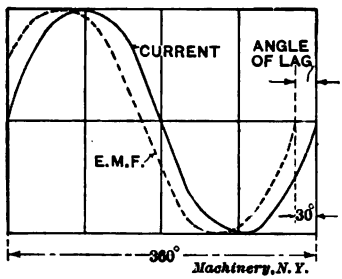

Fig. 9. Current Leads Electromotive Force

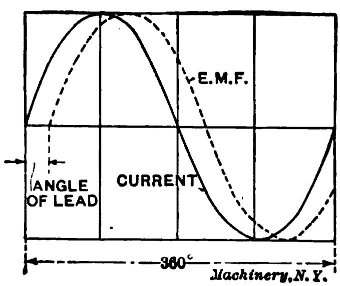

Fig. 10. Current Lags behind Electromotive Force

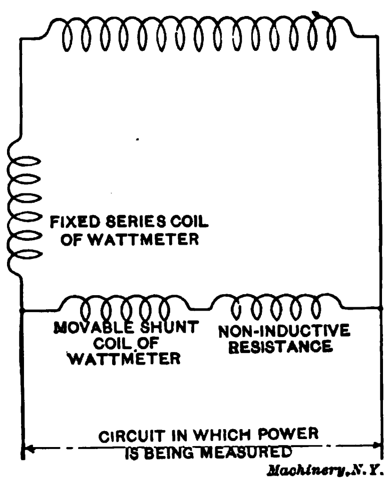

Fig. 11. Diagram showing Principle of Wattmeter

phase. If, however, the changes of current occur later than the changes in the electromotive force, then the current is said to lag behind the electromotive force. Should the current change earlier than the electromotive force, then the current would be said to lead the electromotive force. This is shown graphically in Figs. 9 and 10.

In direct-current transmission the power in watts is determined as the product of the number of volts by the number of amperes in the circuit. In alternating current power transmission this is true only if the current and the electromotive force are in phase, because otherwise the values shown by the voltmeter and ammeter will not be the true values which, if multiplied together, will give the true power. While the power in the circuit at any instant is the product of the

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actual simultaneous values of current and electromotive force, the product of the volts and amperes indicated by the measuring instruments would not give this true value; the product of the readings of these instruments must be multiplied by a *power factor* in order that the true power may be obtained. This power factor is the ratio of the volt-amperes to the watts, and equals the cosine of the angle of lag or lead of the current. In Fig. 9, for example, this angle is 30 degrees. The power factor depends upon the nature of the circuit and the nature of the machines or resistances in it. A large amount of current may be supplied to a circuit having a low power factor, and yet the actual power given to the circuit may be comparatively low. In a case of this kind the readings of the ammeter are too deceptive to be recorded as an indication of the output of the machine supplying the circuit.

The angle of difference in phase between the current and the electromotive force is called ϕ by general usage, and the formula for the power in watts is:

$$W = E \times C \cos \phi$$

in which

W = power in watts,
E = electromotive force in volts,
C = current in amperes.

It is evident that the greater the angle ϕ, the smaller is the cosine of the angle (that is, the power factor) and the less is the total power obtained from a given current and voltage. Hence a decided difference in phase between current and electromotive force is detrimental to the power output. This difference in phase is due to the inductance and consequent impedance in the line. (See Part I of this treatise, MACHINERY'S Reference Series No. 73).

To show a simple case of the influence of lag on the part of the current, take an instance of 100 volts and 10 amperes operating in the circuit. If there is no difference of phase, the two power components operate simultaneously and the total energy $= 10 \times 100 \times \cos 0° =$ 1,000 watts. If inductance causes a lag of 10 degrees then the total watts $= 10 \times 100 \times \cos 10° = 985$. If the inductance causes a further increase in lag, until it reaches a value equal to 30 degrees, the true watts are $10 \times 100 \times \cos 30° = 866$ watts.

The power factors in these cases are respectively the ratios between the true watts and apparent watts or $1{,}000 \div 1{,}000$, $985 \div 1{,}000$, and $866 \div 1{,}000$. The figures are therefore 1.00, 0.985 and 0.866. The power apparent with ammeter and voltmeter would be 1,000 watts.

The Wattmeter

As already mentioned, power measurements cannot be made by an ammeter and voltmeter for the obvious reason that these instruments take no cognizance of the difference of phase of current and electromotive force. The wattmeter, however, is contrived to meet this requirement and gives readings of the true power in watts. A diagram showing how this device is constructed is shown in Fig. 11. There are,

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in the wattmeter, a movable coil and a fixed coil. The movable coil is placed as a shunt across the terminals when the meter is used. It has in series with it a non-inductive resistance. The fixed coil is placed in series with the circuit. Under these conditions the instrument has two currents operating in such a manner that the force required to hold the movable circuit with its axis at right angles to that of the fixed coil will be proportional to the product of the mean value of the currents, respectively. This force is indicated by hands on dials on the face of the instrument. The wattmeter gives the net result

Fig. 12. Moderate-speed Revolving-field Alternator

of the power in the circuit. The conditions required for obtaining successful results, as given by Prof. J. A. Fleming for the operation of a wattmeter, are covered by the following statement: "The current through the series coil of the instrument must have the same value as the current through the circuit to be measured, and the current through the shunt coil of the wattmeter must be exactly in step with the difference of potential between the ends of that shunt circuit; in other words, the shunt circuit must be strictly non-inductive. This can only be secured by winding the movable coil of the wattmeter with no very large number of turns."

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Methods of Driving Alternators

Alternators may be driven from a steam engine or other source of power by being belted to the latter, or they may be direct-connected to the original source of power. This latter method is, perhaps, the most commonly used in modern plants. In Fig. 12 is shown a small moderate-speed revolving-field alternator arranged for being direct-connected to the driving engine. This alternator is provided with a direct-connected exciter for furnishing the current to the field. This particular type is made by the General Electric Co., and may be made for delivering either single-, two-, or three-phase current.

In Fig. 13 is shown a generator direct-connected to a vertical single-cylinder engine. In Fig. 14 a generator is shown direct-connected to

Fig. 13. Generator Direct-connected to Engine

a low pressure Curtis steam turbine. In Fig. 15 is shown a gasoline electric generating set of 25 kilowatts capacity of the type made by the General Electric Co.

Transformers

Transformers serve the function of changing the voltage of a current. If the change is from a low voltage to a high voltage, the transformer is termed "step-up" transformer, and if the change is from a high voltage to a low voltage the transformer is termed a "step-down" transformer. One of the features which makes the alternating current especially useful for power transmission is the fact that it readily

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lends itself to transformation of voltage either up or down. When the electric current has been generated by the alterator and before it enters the power line, all of the energy is let into the transformer to

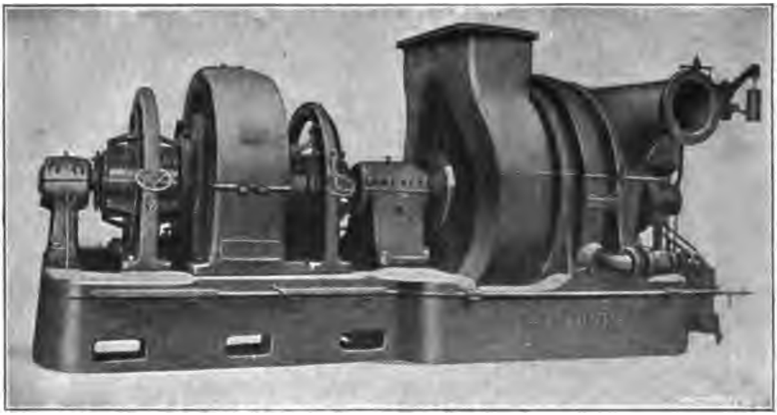

Fig. 14. Generator Direct-connected to Curtis Steam Turbine

be "stepped-up" to a high voltage, at which it is transmitted through the line. At the end of the power transmission line it passes into

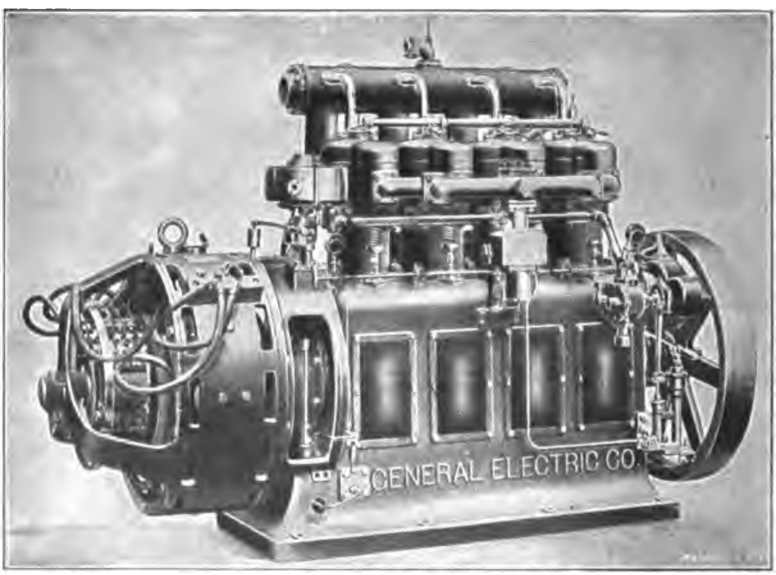

Fig. 15. Gasoline-electric Generating Set

another set of transformers before being sent into the distributing lines, and is "stepped-down" to a safe voltage.

The transformer consists in its simplest form of two coils of wire

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wound upon an iron core. One coil is called a *primary* and is supplied with an alternating current at a certain voltage. When this current passes through the primary it causes the iron core enclosed in it to be magnetized and thus generates a current in the other coil, which is called the *secondary*. The current in the secondary may have a voltage greater, equal to, or less than the voltage in the primary coil depending upon the relative number of turns of the two coils. When the voltage is to be raised, the number of turns in the primary must be less than the number of turns of the secondary. The ratio between the number of turns in the two coils is practically the same as the ratio between the two voltages. A step-down transformer, of course, is con-

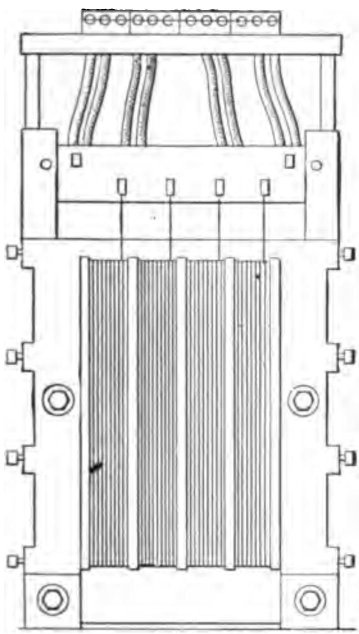

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Fig. 16. General Appearance of Large Size Transformer

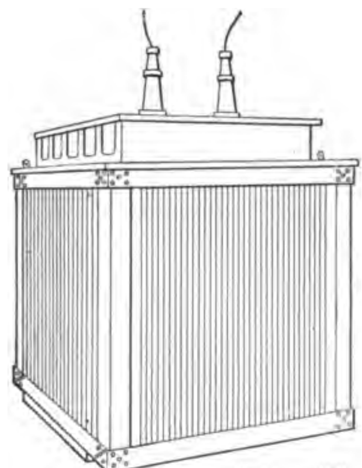

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Fig. 17. Case for Transformer shown in Fig. 16

structed in a reverse manner; that is the number of turns in the primary must be greater than the number of turns of the secondary. When a transformer is used for either increasing or decreasing the voltage, one of the coils consists of a great number of turns of comparatively small diameter wire, well insulated, through which passes a small current at a high voltage. The other coil, consisting of a few turns, is made of heavy wire, so as to permit the passing of a current of greater strength at low pressure.

As an example of the action of a transformer assume that a current of 3,000 volts is to be reduced to 100 volts. The number of turns would then be in the ratio of 30 to 1. The ratio of the voltages is the same

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as the ratio of the number of turns, because, apart from the inevitable losses in the transformer, the power put into it and that taken out will be practically equal. Assume that we want to take out of the secondary 100 amperes at 100 volts. We then must put into the primary at least 5 amperes at 2000 volts, the product of the number of amperes and volts being the same, or 10,000 in each case.

High Voltage Transformers

The introduction of the polyphase motor of Tesla's design and the development of a high insulation, high-pressure transformer went hand in hand with the sudden augmentation in the number of successful power transmission plants installed. High pressure transformers came into vogue to meet a necessary requirement in transmission plants. They run in sizes from about 10 to over 500 K.W. capacity. The obtaining of high insulation is accomplished by building up both primary and secondary in the form of a series of flat coils of few turns per layer, but many layers, and plunging all into oil. According to the data supplied by the manufacturers of these transformers, the advantages of this construction are as follows:

1.—It divides the total electromotive force between several coils, reducing proportionately the strain within an individual coil.

2.—It divides the electromotive force in a single coil between many layers, thus reducing the potential between adjacent layers.

3.—It enables the coils to be spread apart at the ends so that a very large surface is exposed to the oil, thus providing ample radiating facilities and most thoroughly insulating the bent part of the coils.

4.—The regulation of the transformer is greatly improved.

5.—The windings may be connected in series or in multiple, giving a wide range in electromotive force.

6.—In case of damage to a coil, another one may be substituted without trouble, and without returning the transformer to the shop.

The use of oil is admitted to be the solution of the insulation problem when discretion is employed in the design of the coils themselves. It insulates, and also conducts away excess heat very rapidly. The difficulty of handling 30,000 volt transformers is self-evident in case of temporary injury or overload. The construction therefore must be of the best character to preserve its integrity under the strain of heavy service. The development of heat arising from the copper wire can be limited by designing the coil to have a small C^2R loss. The heat due to hysteresis and eddy currents in the core, that is, useless currents produced in the core by the currents flowing around it, can only be controlled by fine lamination and the use of a very high grade of soft iron. The iron has been shown to deteriorate through use and become in a sense inefficient. It takes more energy to magnetize it under these conditions than iron which a test has demonstrated to be free from this phenomenon. To prepare iron for use in transformers a special treatment is necessary. Neglect of this will lead to a heavy waste of energy in the transformer a short time after being put into service. Curves showing the relationship between efficiency and load

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will indicate the rapid rise in efficiency with a relatively light load. They also serve to show the tendency to rise or fall in efficiency with an increasing load up to the full 100 per cent capacity.

A transformer of large size, though efficient, will waste a great deal of energy, which appearing as heat, must be disposed of A 100 K.W. transformer, for instance, wastes 5 per cent or 5 K.W. This amount of heat will act destructively upon the transformer in the course of

Fig. 18. Transformer for High Voltage

time and seriously affect its life. Radiating ribs are therefore supplied to the containing vessel or case, facilitating the radiation of the heat. Corrugations are also employed to increase the surface for the same purpose. High pressure, self-cooling transformers for heavy service are now employed extensively on two and three-phase lines as well as for single-phase. In Fig. 16 is shown the general appearance of a transformer of large size, and in Fig. 17 the case for this transformer. Fig. 18 shows a General Electric transformer for high voltage.

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Two additional cases arise in power transmission plants: First, where two-phase currents are to be transformed into three-phase, and three-phase into two-phase, and second, where the employment of transformers in connection with rotary converters is necessary for the special purpose of meeting voltage changes without difficulty. In this latter case, the call for changes of voltage in the direct-current would necessarily mean proportionate changes in the alternating current. A transformer with a means of changing the ratio of the primary and secondary winding covers this situation successfully. By bringing connections out from the various sections of the transformer to an index and dial, regulation in this respect is readily secured.

Transformers for producing potentials of from 100,000 to 150,000 volts are used for obtaining the high pressure required for testing insulating materials for high voltages. These transformers are built along lines similar to those outlined in the foregoing paragraphs.

Rotary Converters

The rotary converter is used principally for transforming an alternating current used in the transmission of power over long distances into direct-current for use in the distributing lines The rotary converter is similar in construction to a direct-current dynamo. The construction is briefly as follows: On one end of the armature shaft a commutator is mounted and on the other end a number of collecting rings, that is, rings used for collecting the impulses of alternating current. These rings are connected to points at an equal distance apart in the armature winding. Hence the armature of the rotary converter is provided with a commutator the same as a direct-current generator, and with collecting rings the same as an alternating current generator or alternator. Brushes are provided, bearing against the commutator on the one side and against the collecting rings on the other side. When alternating current is received at the collecting rings it will cause the armature to turn when brought up to speed. The converter becomes, in fact, what is called a synchronous motor, a machine which will be described later. Direct-current can now be obtained at the commutator end.

This is the most common use for the rotary converter, but it may be stated that the rotary converter is, perhaps, the most flexible and adaptable of all electrical machines. It may be used in at least nine distinct ways. Supplied with alternating current it will deliver direct current as just described. Supplied with direct current it will deliver alternating current. Supplied with alternating current it will operate as a simple synchronous motor. Supplied with direct current it will operate as a direct current motor. If driven by mechanical power it can be made to deliver either direct current or alternating current, and it is possible to have it deliver current of both kinds at the same time. The reverse of this is also possible. If supplied with alternating current it may run as a motor delivering mechanical power, and at the same time deliver a direct current from its commutator, and if supplied with direct current it may run as a motor delivering mechanical power and at the same time deliver an alternating current.

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Ordinarily, however, the standard type of rotary converter is not built to receive or transmit mechanical power, but is designed to be used strictly as a transformer or converter of electrical energy, that is, for transforming alternating current into direct current, or direct current into alternating current. In the case when the rotary converter is used for receiving alternating current and delivering direct current, it is usual practice to extend the shaft carrying the armature of the rotary converter so that on the same shaft may be mounted a small induction motor for starting purposes. The induction motor will be referred to in detail later. When the rotary converter is employed for transforming direct current into alternating current a small starting exciter may be required on the extension of the armature shaft.

Three methods may be used for starting rotary converters transforming alternating current into direct current. They may be started under the same conditions as a synchronous motor. This motor, as has already been mentioned, develops a satisfactory torque only after having been brought up to normal speed. For this reason the method of starting the rotary converter by connecting it to the alternating current circuit is objectionable, although feasible, because it requires a large current from the mains which may affect the running of other apparatus connected to the same circuit. Hence self-starting rotaries are permissible only when the capacity of the converter is small compared with the total capacity of the generating plant.

The second method for starting a rotary converter of the class mentioned is to connect it to a direct-current circuit, starting it as a direct-current motor, and then, when it has reached a speed corresponding to synchronism, to connect it to the alternating current circuit. This method is preferable to the first one, but the third method which is very satisfactory and the most usual one, is to start the rotary converter by means of an induction motor which is mounted on the same shaft as the armature of the converter, as already mentioned. When the rotor of the converter has been brought up to synchronous speed by this method it may be connected to the alternating current circuit. This method possesses several advantages, the most important one of which is that the only demand for current from the circuit is that occasionally required for the small induction motor.

One of the advantages of the rotary converter is that when properly designed it will maintain a practically uniform voltage, and is not liable to produce such drops in voltage as usually occur when current is supplied direct from a generator and the load increases. This permits a practically constant voltage to be maintained in the circuits supplied by a generator independent of the variations in load on the circuit supplied from the converter.

Alternating Current Rotaries for Polyphase Circuits

The transmission of electrical energy over great distances has developed with the increasing perfection and adaptability of the rotary converter. A power station, situated at a distant point, may by this means distribute its power with relatively great economy over an area

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beyond vision from its site. Certain standard voltages and frequencies are employed, as follows: Alternations 3,000, 3,600 and 7,200 per minute, corresponding to voltages of 125, 250 or 550 volts as required. The Standard Westinghouse two-phase rotaries, according to their bulletin, receive at their collector rings, about 0.7 of the voltage given out at the commutator as a direct current. With a three-phase rotary at the collector rings, the ratio is about 0.6 of that given out at the commutator end. Sparking is almost entirely absent from this class of machines and changes in speed are in strict proportion to the frequency of the current from the central station. The result of too swift variations in frequency causes "hunting" or pulsatory movement due to more

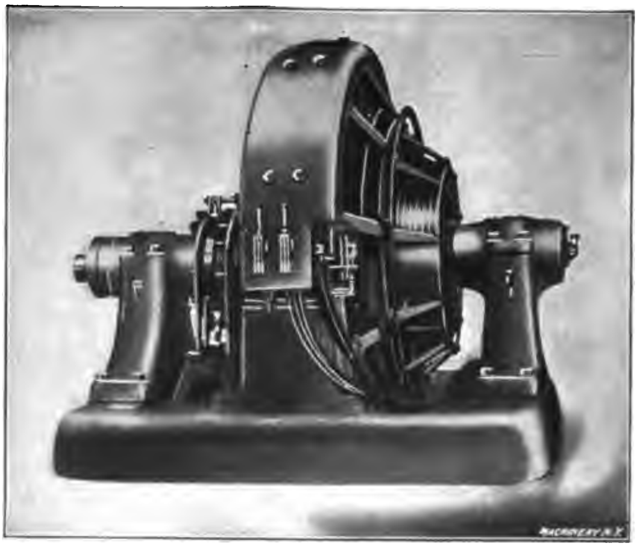

Fig. 19. Rotary Converter

rapid changes in frequency than can be responded to by the rotary. Fig. 19 shows an illustration of a rotary converter as made by the General Electric Company.

Synchronism

When two alternators run at exactly the same frequency and have the same voltage, they are said to be in synchronism with each other. When alternators are used, for example, for lighting circuits, it is necessary to run them in parallel with each other, and before this can be done without disturbing the voltage, they must be synchronized, that is, must be run so as to have exactly the same frequency, the same voltage and be "in step." In order to determine that the alternators run in synchrony with each other, a device called a synchronizer is used. Various types of these devices are employed. In Fig. 20 a diagrammatical sketch of one type of synchronizer is shown. This synchronizer consists of a transformer with two primaries and one second-

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ary. One primary is connected to the current supplied from the first alternator, and the other primary is connected to the alternator that is to be switched in, that is, the alternator which is to run in parallel with the first alternator for supplying the current to the same circuit. The secondary of the synchronizer has a lamp placed in series as shown in the illustration. When the speed or frequency and the voltage of the alternator to be thrown in are right, then, if the two voltages are not in phase, the effect will be a blinking of the lamp on the synchronizer. By gradually adjusting the speed of the machine to be thrown into synchrony, it is brought very nearly into synchrony, that

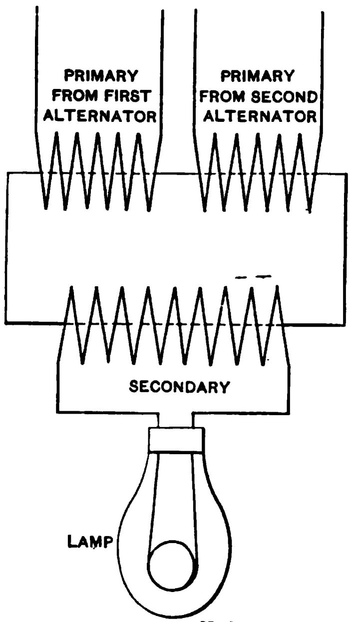

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Fig. 20. Diagrammatical View of one Type of Synchronizer

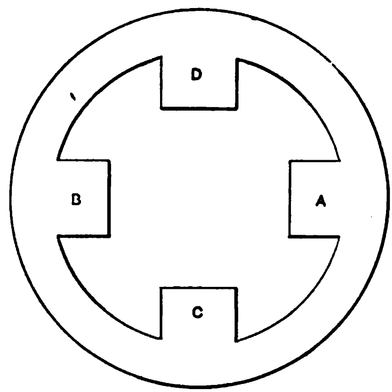

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Fig. 21. Diagrammatical View showing the Means for Obtaining a Rotating Magnetic Field

is, several seconds may elapse between the periods of maximum and minimum brightness of the lamp. At the moment when the lamp has a maximum brightness, and the voltage is the same, the switch is closed and the lamp now glows steadily, showing synchronism.

Motors for Alternating Current

Motors for alternating currents may be of two kinds, either synchronous or induction motors. A direct-current generator will run as a motor when it is supplied with direct current, but an alternator will not run as a motor or drive another alternator as a motor unless the two machines in series are working in synchronism, or, as just explained, are running in exact accord as regards the varying phase or alternations of the current. For example, if we have two single-phase

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alternators of the same kind and type, and one is driven as a generator, the other can be driven as a motor, providing it is first run up to such a speed that its alternations are exactly the same as those of the alternator running as a generator. If at the time when the two machines run at the same speed, the one running as a motor is connected to the circuit of the one running as a generator, then it will continue to run without being thrown out of synchronism. Hence a synchronous motor may be defined as one which has its field magnets excited by a direct current, its armature fed by an alternating current, and which must be started by some exterior means, until it has the same speed as the generator supplying current to it. Hence it is not a self-starting motor, with a single-phase current. With two- and three-phase currents it is possible, however, to produce such effects that a motor will start and run up to speed, and run under load in perfect synchronism with the supply. Such a motor is called an induction motor.

Synchronous Motors

As has already been mentioned, any alternator may be used as a motor, provided it be brought into synchronism with the generator supplying the current to it. The method of bringing an alternating current motor into synchronism with the generator is similar to the operation of bringing two generators into parallel. The field must be supplied with direct current and the field circuit left open until the machine is in phase with the generator. In case the number of poles of the motor is the same as the number of poles of the generator, then the two will, of course, run at the same speed when in synchronism. But if the number of poles of the motor is different, the speed of the motor will be equal to the speed of the generator multiplied by the ratio of the number of poles of the motor to that of the generator.

While two- and three-phase synchronous motors may be made self-starting, it is considered better practice to bring the machines up to speed by independent means, before supplying the current. The machines may be started by a small induction motor, the load on the synchronous motor being thrown off, or the field may be excited by a small direct-current generator belted to the motor. This generator is then used as a motor for starting the machine. Current to run it is frequently taken from a storage battery. The load has an important effect in the operation of synchronous motors. If such a motor is properly regulated as to the load, its power factor will equal 1, but if the load varies, then the current in the motor will either lead or lag behind the electromotive force, and the power factor will vary accordingly. If the motor should be so overloaded that there is a decrease of speed, then it will immediately fall out of step with the generator and stop. One method used for obtaining a power factor nearly approaching 1 is to use a synchronous motor on the same circuit with an induction motor. By increasing the field of excitation, the synchronous motor in this case may be made to have a current which leads the electromotive force, while the induction motor will cause a lag. The two effects will thus tend to neutralize or balance each other, with the effect that the power

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factor will approach 1. Synchronous motors are not satisfactory when the required speed is variable, or the load changeable. They are used to best advantage for large units of power at high voltages when the load and the speed are constant. The disadvantages of the synchronous motor are its inability to start under load and the necessity of direct-current excitation.

Induction Motors

An electromagnet which is supplied with alternating current produces an alternating field which varies in intensity from a maximum in one direction to a maximum in the opposite direction. If two electromagnets are so placed that they act at right angles upon the same air space and if they are both supplied with alternating current of the same phase and periodicity, the two magnets will produce an alternating field which is the resultant of the two fields due to each magnet separately. Now if the phase of the current in the two electromagnets is different, the other conditions being the same for each, then a so-called rotating field will result which will vary its direction continuously and which may be made to retain a uniform strength. This rotating field is the principle upon which the use of the induction motor, which will be described in the following, is based.

The production of a rotating magnetic field may be explained by referring to Fig. 21. In this illustration *A*, *B*, *C* and *D* are the poles of an induction motor, *A* and *B* being one pair wound from one pair of wires of a two-phase alternating circuit, while *C* and *D* are wound with the other pair of wires, the two phases being 90 degrees apart. At a given instance *A* and *B* will receive the maximum current, making *A* a north pole and *B* a south pole. At this moment *C* and *D* are demagnetized and the magnetic field is directed in the direction from *B* to *A*. As the cycle of the current progresses, the magnetic flux at *A* decreases, while that at *C* increases, so that the magnetic field is moving or rotating in a clock-wise direction towards *C*. It will be seen that a complete rotation of the field is performed during each complete cycle of the current, and if an armature is placed within the poles it will be caused to rotate simply by the shifting of the magnetic field, without the need of using any collector ring on the armature, or supplying it with current from an outside source. It should be noted that the expression *rotating magnetic field* refers to the magnetic condition within the poles, and that this expression must be distinguished from the expression *revolving field*, which refers to the mechanical operation of the part of the machine containing the field magnets.

In an induction motor that portion of the machine to which current is supplied from an outside circuit is termed the field or the primary. That portion of the machine in which currents are induced by the rotating magnetic field is termed the armature or secondary. Either the primary or the secondary may be the revolving part. In the more modern machines the armature or secondary revolves.

A common type of armature is that known as the "squirrel-cage" type, which consists of a number of copper bars placed on an armature core

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and insulated from it. On each end the bars are connected by means of a copper ring. In all induction motors the field windings are so arranged that a number of pairs of poles are produced. This is a necessary requirement in order to bring the speed of the rotating field and the rotor down to a practical limit. If, for example, only one pair of poles were employed, then with a frequency of 60, the revolutions per minute of the rotating magnetic field would be 3600.

It should be noted that the rotor or revolving part of an induction motor does not revolve as fast as the rotating magnetic field, except in cases where there is no load on the motor. When loaded, there is a slip between the rotating field and the rotor, this slip being necessary in order

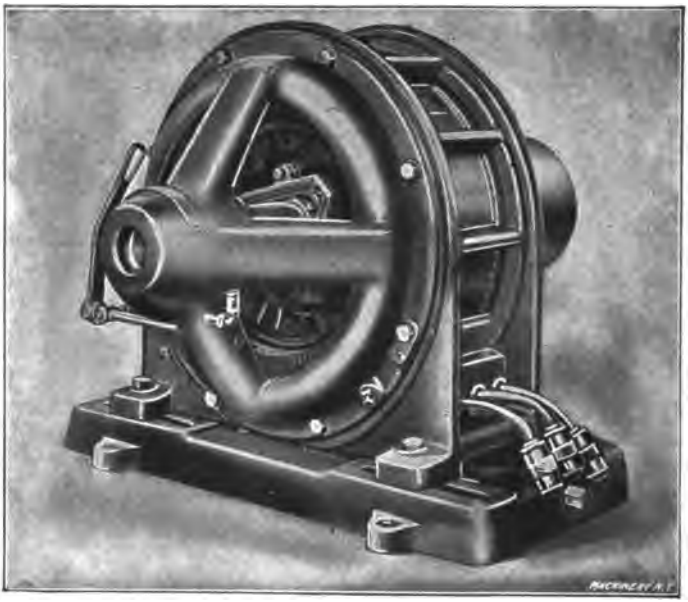

Fig. 22. Induction Motor

that the lines of force of the magnets may cut the conductors in the rotor, and thus induce currents without which motion would not take place. Another fact to be noted in connection with the induction motor is that the current required for starting the motor under full load is from 7 to 8 times as great as the current for running the motor under full load. Induction motors should be run at as near their normal primary electromotive force as possible, because the output and the torque are directly proportional to the square of the primary pressure. As an example may be mentioned that a machine which will carry an overload of 50 per cent at a normal electromotive force, will hardly carry its full load at 80 per cent of the normal electromotive force.

From the description of the construction of the induction motor it is apparent that it is an electric motor whose action depends upon the in-

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duction of an electric current in the armature. The alternating current in the field magnets induces currents in the windings of the armature, and these induced currents produce electro-magnetism in the core of the armature. The fact that the electro-magnetism in the armature is due solely to induction is the reason for the name of the motor. The windings on the armature are connected in parallel and are, so to speak, short-circuited, that is, they have no connection with any outside circuit. An induction motor is frequently termed an asynchronous motor. In Fig. 22 is shown an induction motor made by the Sprague Electric Co.; this motor is of 50 horse power capacity.

Single-phase Induction Motors

A single-phase alternating current produces an alternating and not a rotating magnetic field, as has already been mentioned. If, however, the rotor or armature of a single-phase motor is made to rotate rapidly while the stator or field is supplied with an alternating current, the currents induced in the rotor conductors will themselves produce a magnetic field, and since this field will be out of phase with the primary field, the two magnetic fields, due to the stator and rotor, will together form a rotating field, and the action of the motor will then resemble that of a two-phase motor. In order, however, to get the rotor to revolve in the first place, a special device which generally takes the form of an auxiliary winding supplied with current through a resistance giving it a difference in phase from the main current, is employed. This auxiliary winding is switched out when the rotor has attained sufficient speed.

Switchboards

The switchboard has been aptly described as the heart of an electric power generating station. All the currents generated by the various electrical machines are led to it, and from it radiate all the lines through which the electrical current is distributed. There are a great number of types of switchboards, and it is not possible to describe them in any but a general way.

The purpose of the switchboard is to concentrate or centralize the means of controlling the energy developed in a power station, and it provides means for controlling, distributing, and measuring the current; it offers, as well, a means of protection against injury to the apparatus. The switchboard should be so located that the person or persons in charge of the plant may have a full view of the machines and the switchboard at the same time. The switchboard should also be located so that the connections between the machines and the board may be as short as possible. Sufficient space should be left back of the board so that the operator can easily and safely inspect, repair and adjust the connections, which are made on the back.

Switchboards usually consist of several slabs or panels of marble or slate, on the one side of which are placed the various instruments, handles and switches for the operation of apparatus, and on the other side of which the connections to the apparatus in the power station are made. The sections or panels are each about 2 feet wide and from 6 to 8 feet high. A separate panel is used for each of the various apparatus in the

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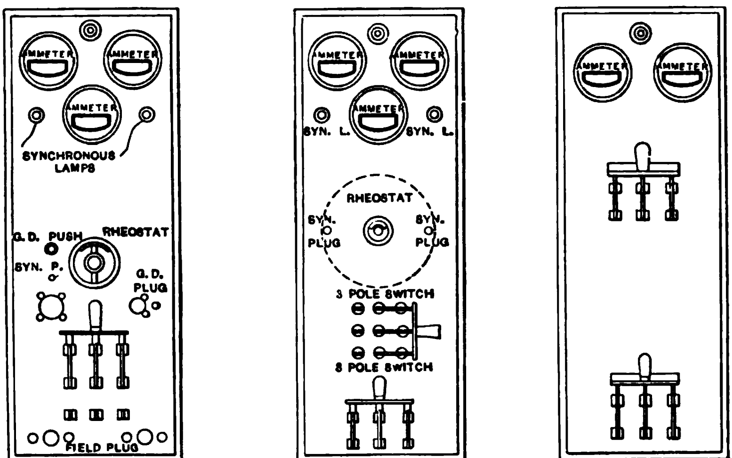
station. There are, for example, generator panels, feeder panels, rotary converter panels, motor panels, etc. A complete switchboard built up of a number of these panels is held together by means of a frame consisting of a rectangular iron support resting on more or less ornamental legs. There is usually an open space of about two feet between the floor and the lower part of the frame, which supports the panel. The construction of the panels is usually such that extra panels can be added as required.

The reason why marble is used for the panel is on account of the necessity of using a strong insulating and fire-proof material. Slate may be used instead of marble for circuits which are not above 1000 volts. If slate is used for circuits over 1000 volts, the sections of the circuits which carry the high potential current must be insulated from the panel. The reason for this is that slate is liable to contain veins of



Machinery, N.Y.

Fig. 23. Various Arrangements of Switchboard Panels

lower insulating materials. Marble panels are left in their natural white state, whereas slate panels are finished in oil or black enamel. The black oil finished slate panel gives a neat appearance, and harmonizes with the finish of the devices mounted upon it. Marble, however, is stronger, and as already mentioned, is a much better insulator than slate, but on account of the fact that its polished surface will show oil stains, it is more difficult to keep it looking clean and neat. Sometimes marble panels are black enamelled for this reason, and then present a dull black finish.

When the instruments which are to be used on the switchboard are mounted on it, similar instruments and devices on the different panels standing side by side should be located at the same height, as this tends to give the panels a symmetrical and pleasing appearance. The instruments that are mounted on the switchboards are, as a rule, as follows: Indicating voltmeters, field ammeters, swinging voltmeters, switches,

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rheostats, synchronizers, ground detectors, fuses, circuit breakers, transformers, compensators, and wattmeters.

The general arrangement of the various instruments on the switchboard is generally as follows: Circuit breakers and fuses are placed near the top of the panel; the reason for this is that if any arc should rise, no injury will be done to the adjacent devices or to the operator. Beneath the circuit breakers are located the various volt- and ammeters. About the middle of the panel are placed the hand-wheel for operating the rheostat, the field switches, etc., as well as the large recording wattmeters. Of course, this arrangement is often departed from. A further description of switchboards will contain little more than a description of the various apparatus which it carries. The types of switchboards used in different stations vary greatly, so that only general statements can be made relating to their arrangement and design. In Figs. 23 and

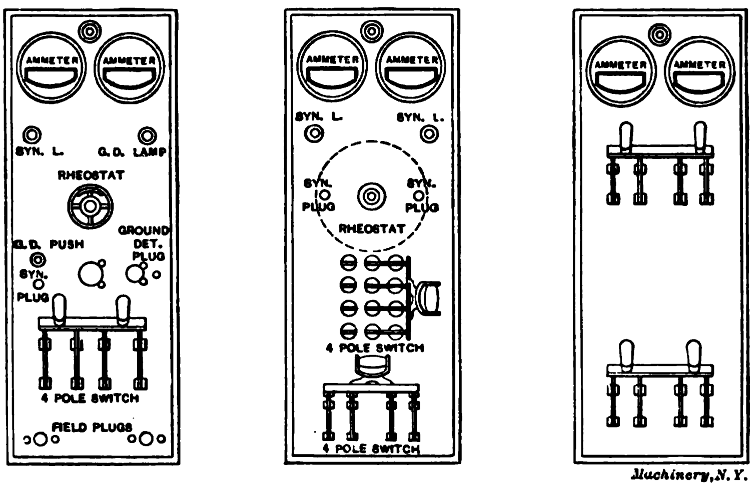

Fig. 24. Various Arrangements of Switchboard Panels

24 are shown various arrangements of switchboard panels, and Fig. 25 shows the general appearance of a switchboard for an alternating current installation.

The importance of the switchboard is realized when it is remembered that it offers a check upon the efficiency and economy of the whole power installation. All the machines have been designed to operate most economically under certain loads, and the switchboard provides the indicating and recording instruments by means of which it becomes possible to determine if the machines are working under the most advantageous conditions. A record can also be kept of the total output. The protecting devices contained on the switchboard are also of importance in that they prevent injury and economical losses due to unforeseen causes. It is highly important that these safety appliances are kept in proper repair so that they are always reliable, especially when they are of the automatic type. If they are not kept in good condition they may be a

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greater source of danger than of benefit, because the operator will naturally rely upon them, and hence invite difficulties which otherwise might have been guarded against.

Instruments Used on the Switchboard

Voltmeters are employed for the purpose of enabling the switchboard attendant to obtain the voltage of any section of the system, or of any

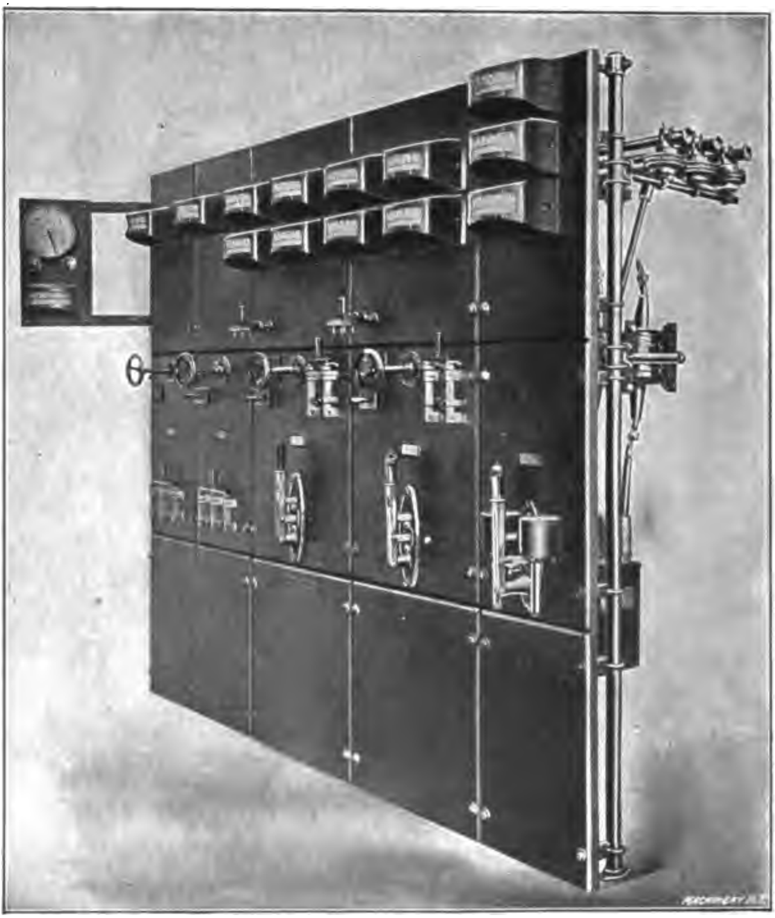

Fig. 25. A Complete Switchboard

generator, by the use of a plug switch inserted in a voltmeter receptacle. Swinging voltmeters are mounted on an arm attached to a bracket fastened to the side of the panel and can be swung back and forth. The mounting is similar to that of the synchronism indicator shown in Fig. 26. When a second generator panel is installed for the purpose of operating more machines in multiple, the use of another

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voltmeter becomes necessary, and this voltmeter is then mounted on the swinging arm so as to occupy a place beside the first. The two voltmeters can thus be easily compared, and any differences in voltage between the two generators seen at a glance. Ammeters are used for measuring the current and are mounted on the switchboard, the same as the voltmeters. The general appearance of the ammeter and voltmeter is practically the same.

Switches are used for making or breaking contacts so as to connect and disconnect one part of a circuit with another. It is evident that switches are required to act quickly, as the time for making the contact and the abruptness in breaking the contact are matters of great importance.

The rheostat is often mounted on the back of the generator panel or in proximity to it. There are two rheostats for alternating current machines, one for the exciter and the other for the generator. Hand-

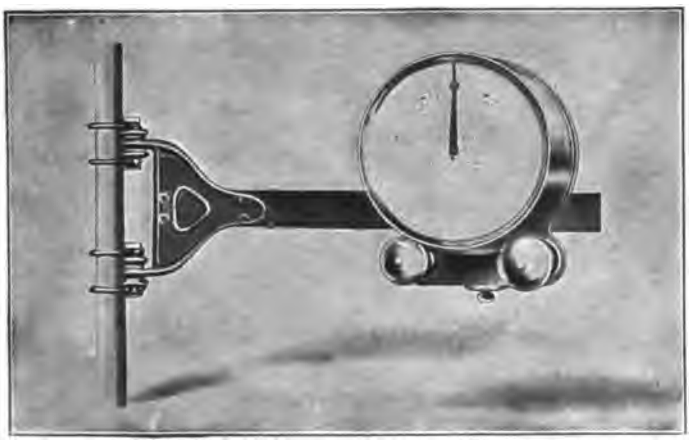

Fig. 26. Synchronism Indicator

wheels are mounted on the face of the panel, which are employed for turning the contacts. These latter do not appear on the front side of the panel; only a dial with a movable index is seen on this side. The dial index shows the relative value of the resistance when the rheostat is operated by the hand-wheel. In some instances the rheostat is placed at a point some distance from the switchboard, in which case only the dial with its various connections and the hand-wheel are placed on the panel.

Synchronism Indicator

The method of bringing two alternators into synchronism by means of an electric lamp has already been referred to. Any satisfactory device used for synchronizing two or more alternating current machines should properly perform three distinct functions. It should indicate whether the starting machine is rotating slower or faster than the other machine; it should indicate the amount of difference in speed;

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and it should accurately indicate the moment when synchronism and coincidence in phase of the two machines occur. A synchronizing lamp does not perform the first function. It performs the second function properly, and the third function only approximately. For this reason special instruments called synchronism indicators have been brought out. The pointers on these instruments move around a dial like the hands of a clock, and the angle of the pointer's displacement from the vertical position is a measure of the angle of phase difference between the two sources of electromotive force to which the device is attached. Hence if the machine to be brought into synchronism rotates too fast, the pointer will move in one direction, and if it runs too slow, the pointer will move in the other direction. When coincidence in phase takes place, the pointer remains in a vertical stationary position. An instrument of this kind mounted on a swinging bracket is illustrated in Fig. 26.

Ground Detectors and Fuse Blocks

A ground detector is a device by means of which any leg or part of the circuit may be tested for grounds. Two lamps in series, connected to the ground at the point of connection between the two lamps, and so arranged by means of a switch that a test may be made, constitutes the general character of the apparatus. Whichever lamp burns brightest indicates the position of the ground. If the lamp connected to the right hand leg burns brightest, the left leg is grounded, and *vice versa.*

Fuses for alternating current service are generally mounted on porcelain backings, which in turn are contained in an iron box. They serve the purpose of opening the circuit when too heavy a current tends to flow through it. They consist of some easily fused metal which melts when a strong current flows through it, and thus disconnect the circuit. It is said that the fuse "blows" when the metal thus melts. When blowing, the operator is protected from injury by the position the fuses occupy in the porcelain foundation. A type of porcelain tube is employed which forms part of the porcelain foundation and which occupies a front position in the forward part of the fuse block; this contains the fuse and protects the lineman whether the box is near his hands or not, or whether it is opened or closed. In some designs of fuse blocks the porcelain tubes are readily removable. As they contain the fuse itself, it is evident that the removal of this tube and the insertion of another involves no risk of dangerous contact. The fuse, when blowing, expels the volatilized metal through the porcelain ends and thus protects the device from injury. It is to be understood that a fuse box must be waterproof. The presence of moisture would rapidly invite electrolytic and other actions. Heavy grounds, ultimately resulting in short circuits, would also be incurred.

Circuit Breakers

Circuit breakers are mechanical devices used instead of fuses to open an electric circuit when the current exceeds a certain predeter-

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mined value. They are the safety valve of the electric circuit, and prevent an excess of current to enter into a circuit where it would act destructively to the machinery and apparatus. The usual form of the circuit breaker is that of a switch normally held in its shut-down position by a latch and provided with a strong spring which acts in a direction tending to open the switch. A magnet is provided which is capable of releasing the latch and allowing the spring to throw the switch open as soon as the current reaches the danger point, or the value for which the magnet and latch are adjusted. The magnet is a solenoid, that it, it consists of a plunger around which are wound a few turns of heavy wire carrying a current. The current around the plunger magnetizes it, and causes it to move, thereby tripping the latch.

Circuit breakers are used instead of fuses because they are more sensitive; they can be adjusted to open exactly at a predetermined current value with the same precision as a safety valve opens at a given steam pressure. The most important advantage of the circuit breaker, however, is that it requires but a fraction of a second to throw in the circuit breaker switch, while it takes considerable time to replace a fuse. Besides the time gained, it is also much easier to operate in all respects. The only reason why circuit breakers are not used entirely in place of fuses is that their first cost is a great deal more than the cost of fuses. Small fuses are less objectionable than large ones, and for this reason circuit breakers are seldom used instead of small fuses.

The Compensator

The compensator, or as it is often called, the voltmeter compensator, is a device by means of which the voltmeter on the switchboard in the power station may be arranged to show the voltage between the transmission lines at some distant point, usually the point where the current is consumed. The transmission of power involves the sustaining of the correct voltage at the points, not only of distribution, but of consumption as well. The terminals of the feeding system must therefore be watched carefully to remedy any great difference in voltage between them and the station proper.

Losses in Power Transmission

If some estimate is made of the net results of power transmission from a standpoint of efficiency, based upon a general efficiency of 90 per cent per machine throughout the plant, the figures will show a lower efficiency than would be anticipated at first glance. Assuming the engine to deliver 1000 horsepower, the dynamo would yield 900 horsepower; the step-up transformers would give 10 per cent less, or 810 horsepower; the line would give 10 per cent less, or 729 horsepower; the step-down transformers would give 10 per cent less, or 656 horsepower; and the rotary converters and street lines 10 per cent less, or 590.4 horsepower. Higher percentages of efficiency than these are claimed for many plants, but a 30 per cent loss is not to be

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considered as very large from end to end of the complete power transmission system. Of course, the losses are not uniform as in the example above. In some of the apparatus the losses are more than 10 per cent and in some less. But the example above was chosen

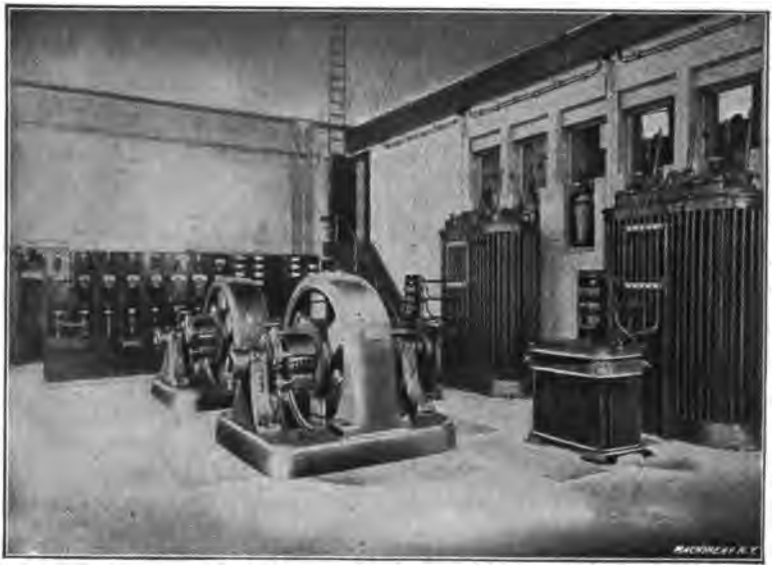

Fig. 27. The Interior of a Sub-station

simply to show the method of obtaining the total efficiency when the losses in each part of the transmission system are known.

In Fig. 27 is shown the interior of a sub-station. As will be seen in the illustration, there are two transformers placed against the wall and two rotary converters in the center of the room. In the back will be seen the switch-boards with their meters, switches and other apparatus.

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CHAPTER III

POWER TRANSMISSION LINES

In the usual type of power transmission plant the power is generated at 2000 or 3000 volts, and is then transformed up by static transformers at the station end of the power line to 10,000 or 15,000 volts. A current of this voltage is then transmitted through the line to the receiving end, where a sub-station is located; the current is then stepped-down to a voltage suitable for the use to which it is to be put. Power transmission lines, hence, carry a very high voltage, and this, in fact, is one of the necessary requirements, both in order to reduce the heat losses and the size of the conductors required.

The material used in the wires is almost always copper, although aluminum is used to some extent. Both of these metals are used in their commercially pure state, and are selected on account of their high factor of conductivity. Aluminum is not as good a conductor as copper and a larger diameter of wire, therefore, is required to carry the same current, but even with this larger diameter the line is lighter than one of copper, on account of the low specific gravity of aluminum, and it is for this reason often used for long distance transmission lines. With the present low price of aluminum, the total cost of the line is not much different from that of a copper line. Aluminum is not used when it is necessary to insulate the wires, because, being larger in diameter, a greater amount of insulation material would become necessary, and this would increase the cost of the line considerably above one consisting of a copper conductor.

The area of copper wires is usually given in circular mils. By a circular mil is meant the area of a circle 0.001 inch in diameter. Table IV gives the area in circular mils of copper wire of various sizes according to the Brown & Sharpe wire gage. This table also gives the diameter and the resistance in ohms per foot. The resistance of an electrical conductor is expressed by the formula:

$$R = L \times f$$

in which R = total resistance in ohms,

L = length of the conductor in feet,

f = resistance of wire of given size in ohms per foot, as found from Table IV.

Square mils are sometimes used for expressing areas. A square mil is the arca of a square whose side measures 0.001 inch. One square mil equals 1.27 circular mil. The diameters of copper wire used as conductors are given in the American or Brown & Sharpe wire gage. Wires of a size larger than No. 0000 are designated by their diameters in inches.

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Effect of Resistance

The effect of the resistance in conductors shows itself in a drop in voltage, this drop being determined by Ohms' law. (See MACHINERY'S Reference Series No. 73, Principles and Applications of Electricity, Part I). There is also a loss of energy proportional to the C^2R loss referred to in the previous chapter. In addition there is a heating of the conductors, due to this energy loss, which is converted into heat. When the conductors increase in temperature the resistance increases, until all the energy generated is lost in heat. For this reason a conductor is capable of carrying only a certain amount of current with a given temperature rise. As a general rule, the current density should not exceed 1000 amperes per square inch of cross-section for copper conductors, but this value is too low for wire of small gage, and is too high for wire of large diameter. As an average, however, it may be used for general estimates.

TABLE IV. DIMENSIONS AND RESISTANCE OF COPPER WIRE

Dimensions			Resistance	
			Ohms per Foot	
American or Brown & Sharpe Gage	Diameter in Inches	Area in Circular Mils	At 68° F.	At 122° F.
0000	0.4600	211,600	0.0000489	0.0000547
000	0.4096	167,800	0.0000617	0.0000689
00	0.3648	133,100	0.0000778	0.0000869
0	0.3249	105,500	0.0000981	0.0001096
1	0.2893	83,690	0.0001237	0.0001382
2	0.2576	66,370	0.0001560	0.0001743
3	0.2294	52,630	0.0001967	0.0002198
4	0.2043	41,740	0.0002480	0.0002771
5	0.1819	33,100	0.0003128	0.0003495
6	0.1620	26,250	0.0003944	0.0004406
7	0.1443	20,820	0.0004973	0.0005556
8	0.1285	16,510	0.0006271	0.0007007
9	0.1144	13,090	0.0007908	0.0008835
10	0.1019	10,380	0.0009972	0.0011140
11	0.0907	8,234	0.0012570	0.0014050
12	0.0808	6,530	0.0015860	0.0017710
13	0.0720	5,178	0.0019990	0.0022340
14	0.0641	4,107	0.0025210	0.0028170
15	0.0571	3,257	0.0031790	0.0035520
16	0.0508	2,583	0.0040090	0.0044790
17	0.0453	2,048	0.0050550	0.0056480
18	0.0403	1,624	0.0063740	0.0071220

Insulation or covering is required for all conductors carrying electrical energy, excepting for wires used on pole lines. Even these wires are, however, often insulated. The insulation may serve the purpose of merely preventing the wires from coming into contact with each other, in which case a simple cotton or silk covering is used. When a high voltage is carried, the insulation serves the purpose of presenting a high specific resistance.

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In speaking of the capacity of a conductor we have meant, so far, its capacity for carrying or transmitting current. The expression "electrostatic capacity" of a conductor, however, is the quantity of electricity that is required for charging the conductor to a given potential, or in other words, it is the quantity of electricity which must be imparted to the conductor as a charge in order to raise its potential a certain amount. The amount of electricity used for this purpose involves, of course, a loss of a part of the total amount of energy sent into the line. When the line is long the capacity may be appreciable. Formulas and tables will be given in the following for its calculation in all cases.

Capacity and Inductance in Power Lines

A power transmission line is affected in two respects, first by the effect of one wire upon the other, and of each of the wires upon the earth, and second by the effect of self and mutual inductance. These two effects are called the inductance and the capacity of the line, respectively, and constitute the losses met with in a power transmission. The capacity, in this case, is what is called the electrostatic or static capacity of the line, as has just been explained above. The capacity may be reduced by increasing the distance between the conductors, or in lead-covered cables, by using an insulating material having a low specific inductive capacity such as paper.

By mutual inductance is meant the inductive effect of one circuit on a separate circuit, the other circuit being in parallel in a power transmission. If, for example, an alternating current flows in one circuit, it sets up an electromotive force in a parallel circuit. This electromotive force is opposite in direction to the electromotive force impressed on the first circuit. The effects of mutual inductance may be reduced by increasing the distance between the circuits, the distance between the wires of the same circuit remaining the same. It is evident that this method is impractical beyond certain limits, when the wires of the two circuits are supported by the same poles. In this case a special arrangement as explained later must be used.

The conditions which make a circuit inductive or non-inductive may be regarded as those which individually or collectively add more or less of a varying magnetic field to the circuit. For instance, a core of iron around which a coil of wire carrying an alternating current is wound is an extreme case of inductance. The removal of the iron core reduces the degree of inductance, and the straightening of the wire from its coiled form still further reduces it. When two straight wires are employed for the purpose of transmitting electrical energy in the form of an alternating current, they have the least effect inductively upon each other when closest together. In other words, if one wire leading out, and the other leading back to the power house, are installed a short distance away from each other, the effects of self-induction are less than when they are widely separated, but a wide separation between high tension wires is relatively necessary as insulation could not otherwise be secured, particularly during conditions of great dampness or severe rain.

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The distance between copper conductors will influence the degree of inductance to an extent indicated by the following figures: For a No. 0 Brown & Sharpe gage pair of wires, run parallel and at the distances of 12, 18, 24 and 48 inches apart, the inductances in each case will be respectively 0.00254, 0.00276, 0.00293 and 0.00331 henry. A line necessarily has a certain amount of induction, which, when its true carrying capacity is estimated, calls for consideration. It is quite evident that the increasing value of high potentials necessitates the use of greater distances between the power lines than would be otherwise necessary. Tests have been made for the purpose of determining the pressure and distance over which spontaneous sparking would result. The results have been tabulated in a case where a wave form of current was employed with the spark leaping between

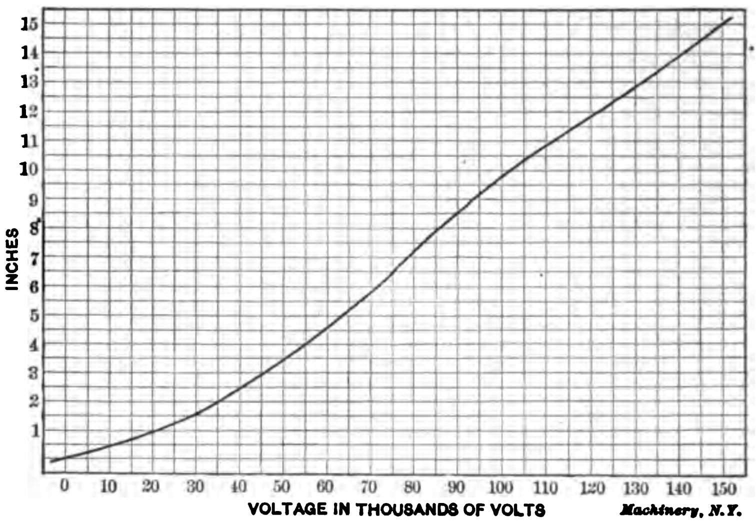

Fig. 28. Chart showing Relation between Voltage and Distance between Conductors

needle points. A chart with a curve showing the relationship between the distance and voltage, with corresponding data, is given in Fig. 28. The diagrammatic form in which these facts are given will give some idea of the conditions resulting from the use of high pressures when the questions of inductance and insulation arise.

Calculating the Inductance Between Wires

Various tests may be made to ascertain the amount of inductance between two parallel wires of copper or aluminum by employing a galvanometer and measuring the results obtained. On the other hand, fairly accurate calculations can be made by selecting and using a reliable and simple formula for the same purpose.

Let $A =$ distance between the wires in inches,

$d =$ diameter of the wires in inches,

$L =$ the inductance in henrys.

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Then the total inductance per mile of circuit is found by the following formula:

$$L = 0.000558\ [2.808 \log \left(\frac{2A}{d}\right) + 0.25]$$

A table can be made up, based upon this formula, in which the inductance is calculated for various distances between wires of different diameters.

The influence of inductance is overcome by the use of concentric conductors, or by conductors twisted around each other. The effects of inductance, unless remedied, are noticeable in the increased impedance in the line and the lag of the current.

The nearness of the conductors in pairs is detrimental in that it causes an increased mutual induction between them. To overcome this difficulty, where it is impractical to increase the distance between the wires, it is necessary to make use of the method of transposition in installing the wires. This consists of the crossing of the conductors at certain intervals so that a neighboring pair of wires remain inductively unaffected by the variations occurring in the first pair.

Capacity of Lines

The static capacity of transmission lines can be calculated by formulas covering insulated lead-covered cables, single conductors with a ground return, or two parallel conductors constituting the total circuit. The formula giving the capacity in microfarads per mile for lead-covered cables is:

$$C = \frac{38.83 \times K \times 10^{-3}}{\log \frac{D}{d}} \text{ per mile.}$$

For a single metallic circuit with ground return:

$$C = \frac{38.83 \times 10^{-3}}{\log \frac{4h}{d}} \text{ per mile.}$$

For metallic conductors running parallel to each other:

$$C = \frac{19.42 \times 10^{-3}}{\log \frac{2A}{d}} \text{ per mile.}$$

where C = capacity in microfarads,
K = specific inductive capacity of insulation = 1 for air, and 2.25 to 3.7 for rubber,
D = inner diameter of lead covering of cable,
d = diameter of conductor,
h = height of conductor above ground,
A = distance between wires.

The capacity of a circuit may be controlled as far as its effects are

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concerned by the introduction of a certain amount of inductance. By this means a neutralization of one by the other is effected successfully. The relationship of the two must be such that $C = 1 \div (2 \times \pi \times f)^2 \times L$, in which f = the frequency, and L = henrys.

Conductors Carrying Power

Conductors for carrying power can only be properly estimated on the basis of their weight, strength, temperature, resistance, capacity and inductance. The cost of the current carrying wire forms a considerable part of the expense of the erection of a complete power transmission line. The balance of the expense lies in the cost of the undertaking with regard to the poles, insulators, etc. The original law laid down by Lord Kelvin has undergone modification. His statement of the situation from an economic standpoint was as follows: "The interest on the cost of the copper of the line must be equal to the cost of the power wasted in the line." If the line cost $100,000, the interest at 6 per cent being $6,000 represented the dollars and cents value of the power that could be wasted in it without overstepping the economic law governing the best conditions of practice. The best conditions of practice, however, as outlined by the best engineering done in this field, show an expense in the insulation which far exceeded the anticipations of the theorists originally dealing with the subject. Copper and insulation are of greater importance as regards the integrity of the plant and its serviceability for continued power transmission than was formerly believed, because of the extraordinary high pressures employed to secure economical transmission.

The following formulas are recommended by one of the largest electrical manufacturing concerns in the United States. They relate entirely to the questions involved in power transmission, namely:

1. The area of the conductors in circular mils.
2. The weight of the copper of the conductors.
3. The voltage loss in the line.
4. The current in the main conductors.

The area of the power line in circular mils is obtained by employing this formula:

Area $= (D \times W \times C_1) \div (p \times E^2)$ in which

W = power delivered in watts,
D = distance of transmission in feet (one way),
p = loss in line in per cent of power delivered,
E = voltage between main conductors at receiving or consumer's end of the circuit.

The value of $C_1 = 2160$ for direct current, when $T = 1$, $B = 1$ and $A = 6.04$. The last symbols refer to characters used in formulas to follow. To obtain the value of the current in the main conductors, a formula of the following simple form is used:

$$\text{Current in main conductors} = W \times \frac{T}{E}.$$

When the power circuit carries a direct current $T = 1$. When the

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system is alternating, the value of T is obtained from the table below, in which it is given for single, two and three-phase currents:

System of Transmission	Power Factor in Per Cent				
	100	95	90	85	80
Single-phase system, value of T=	1.00	1.05	1.11	1.17	1.25
Two-phase system, (four wire), T=	0.50	0.53	0.55	0.59	0.62
Three-phase system (three wire), T=	0.58	0.61	0.64	0.68	0.72

Thus, $T = 1$ for direct current; for single-phase with a power factor of 100 it also equals 1; for two-phase it equals 0.50; and for three-phase 0.58. But ideal conditions like these do not exist in power lines except under extraordinary circumstances. When the power factor is 80, the value of T becomes respectively 1.25, 0.62 and 0.72 with single, two and three-phase currents.

An illustration of this principle of application can be readily made by a case in which it is desirable to know the current in the main conductors with a given amount of power, say 100,000 watts, which is transmitted at a pressure of 10,000 volts by continuous current and single, two and three-phase currents, the power factor for all being 90.

With direct current. Current in main conductors $= 100{,}000 \times \frac{1}{10{,}000} = 10$ amperes.

With single-phase current. Current in main conductors $= 100{,}000 \times \frac{1.11}{10{,}000} = 11.1$ amperes.

With two-phase current. Current in main conductors $= 100{,}000 \times \frac{0.55}{10{,}000} = 5.5$ amperes.

With three-phase current. Current in main conductors $= 100{,}000 \times \frac{0.64}{10{,}000} = 6.4$ amperes.

The relative values in this case, when compared, show differences representing the amount of copper necessary for 10 amperes with direct current, 11.1 amperes with single-phase, 5.5 amperes with two-phase and 6.4 amperes with three-phase. The increase in the copper required with single-phase transmission over that required for a direct current, for equal quantities of power, is the difference between 11.1 amperes and 10 amperes. The weight of additional copper over a long line would readily prove the disadvantage of this if it were not outweighed by other considerations, such as comparatively easy handling as regards insulation. A direct high-tension current is not practical for

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power transmission because of the difficulty in attempting to secure insulation and commutation in direct-current motors under these conditions.

The weight of copper is calculated by the formula:

Pounds of copper $= (D^2 \times W \times C_1 \times A) \div (p \times E^2 \times 1{,}000{,}000)$.

The value of C_1 depends upon the system as does also A. Both are given in the following table, which covers the situation with regard to single, two and three-phase systems:

Systems	Values of A	Power Factor in Per Cent				
		Values of C_1				
		100	95	90	85	80
Single-phase..........	6.04	2160	2400	2660	3000	3380
Two-phase (four-wire)..............	12.08	1080	1200	1330	1500	1690
Three-phase (three-wire)..............	9.06	1080	1200	1330	1500	1690

In the case just cited, where $D = 100{,}000$ feet, $W = 100{,}000$ watts, $C_1 = 2660$, $A = 6.04$, $p = 10$, $E = 10{,}000$ volts, if the weight of copper for the single-phase system is calculated for a distance of 100,000 feet the result would be as follows, with a 90 per cent power factor and a 10 per cent loss.

Pounds of copper for single-phase system $= (100{,}000 \times 100{,}000 \times 100{,}000 \times 2660 \times 6.04) \div (10 \times 10{,}000 \times 10{,}000 \times 1{,}000{,}000) =$

$$\frac{100{,}000^3 \times 2660 \times 6.04}{10 \times 10{,}000^2 \times 10^6} = \frac{10^{15} \times 2660 \times 6.04}{10^{15}} \doteq 16{,}066 \text{ pounds.}$$

If the weight of copper is to be found for a two and a three-phase circuit under the same general conditions, an examination of the table will readily show that A for a two-phase system is 12.08, and C_1 for the same phase with a power factor of 90, has the value 1330. A further examination will show for three-phase, the value for A of 9.06, and for C_1 with a 90 per cent power factor 1330. Arranging the items as before, we have the following data for calculating the weight in pounds of copper of a two-phase system: $D = 100{,}000$ feet, $W = 100{,}000$ watts, $C_1 = 1330$, $A = 12.08$, $p = 10$, $E = 10{,}000$ volts.

Pounds of copper for a two-phase system $= (100{,}000^2 \times 100{,}000 \times 1330 \times 12.08) \div (10 \times 10{,}000^2 \times 10^6) = \dfrac{10^{15} \times 1330 \times 12.08}{10^{15}} =$ 16,066 pounds.

These calculations show no difference in the weight of wire.

The data supplied in connection with a three-phase system with a power factor of 90 are as follows: $D = 100{,}000$ feet, $W = 100{,}000$ watts, $C_1 = 1330$, $A = 9.06$, $p = 10$, $E = 10{,}000$ valts.

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Pounds of copper for a three-phase system $= (100{,}000^2 \times 100{,}000 \times 1330 \times 9.06) \div (10 \times 10{,}000^2 \times 10^6) = \dfrac{10^{15} \times 1330 \times 9.06}{10^{15}} =$ 12,050 pounds.

The variation in weight due to the introduction of a three-phase system suggests the economic reason for its success over other methods. The results show equivalence in weight for a single and two-phase system as stated. The three-phase gives a favorable difference in weight of 25 per cent.

Where three-phase power transmission is a problem of many miles instead of the limited distance of the last examples, a formula is suggested for the weight of copper as follows:

Pounds of copper $= (M^2 \times \text{K. W.} \times 300{,}000{,}000) \div (p \times E^2)$,
where $M =$ the distance of transmission in miles,
K. W. = the total energy delivered in kilowatts.

The power factor is assumed to be approximately 95 per cent.

If, for the purpose of illustrating the application of the formula, the following data are assumed:

$M = 100$ miles,
K. W. = 10,000,
$p = 10$,
$E = 100{,}000$ volts,

then the weight of copper will equal $\dfrac{100^2 \times 10{,}000 \times 300{,}000{,}000}{10 \times 100{,}000^2} = \dfrac{3 \times 10^{16}}{10^{11}} = 300{,}000$ pounds of copper.

The Voltage Drop in the Line

The voltage drop in the line must receive consideration as the factor influencing the commercial aspect of the problem of power transmission more than any other. It is, in fact, the question of wasted energy in the line, which governs its cross-section for a given length. The weight is, therefore, an element governed by distance only in so far as the energy dissipated is duly considered. The greater the drop, the less the weight of copper for a given distance, other things being equal, and the less the drop, the greater the weight of copper required for a given distance under the same circumstances. The formula for the voltage lost in the power line is as follows:

Volts lost in line $= p \times E \times B \div 100$, where, as already stated,
$p =$ per cent loss of power,
$E =$ total pressure of line at the receiving end,
$B = 1$ for direct current.

The values of B for alternating current service, depend upon the size of the wire, frequency of the current and the power factor employed. In Table V values are given for wires 18 inches apart. If the difference in phase between the transmitting and receiving end is not very marked, these figures are reliable. Where the line loss exceeds 20 per cent and large conductors at 125 cycles are employed

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TABLE V. VALUES OF FACTOR B

Size of Wire B. & S. Gage	25 Cycles Power Factor				40 Cycles Power Factor				60 Cycles Power Factor				125 Cycles Power Factor			
	95	90	85	80	95	90	85	80	95	90	85	80	95	90	85	80
0000	1.23	1.29	1.33	1.34	1.52	1.53	1.61	1.67	1.62	1.84	1.99	2.09	2.35	2.36	3.24	3.49
000	1.18	1.22	1.24	1.24	1.40	1.41	1.48	1.51	1.49	1.66	1.77	1.95	2.08	2.48	2.77	2.94
00	1 14	1.16	1.16	1.16	1.25	1.32	1.35	1.37	1.34	1.52	1.60	1.66	1.86	2.18	2 40	2.57
0	1 10	1.11	1.10	1.09	1.19	1.24	1.26	1.26	1.31	1.40	1.46	1.49	1.71	1.96	2.13	2.25
1	1.07	1.07	1.05	1.03	1.14	1.17	1.18	1.17	1.24	1.30	1.34	1.36	1.56	1.75	1 88	1.97
2	1.05	1.04	1.02	1.00	1.11	1.12	1.12	1.10	1.18	1.23	1.25	1.26	1.45	1.60	1.70	1.77
3	1.03	1.02	1.00	1.00	1.07	1.08	1.07	1.05	1.14	1.17	1 18	1.17	1.35	1.46	1.53	1.57
4	1.02	1.00	1.00	1.00	1.05	1.06	1.03	1.00	1.11	1.12	1.11	1.10	1.27	1.35	1.40	1.43
5	1.00	1.00	1.00	1.00	1.03	1.01	1.00	1.00	1.08	1.08	1.06	1.04	1.21	1.27	1.30	1.31
6	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.05	1.04	1.02	1.00	1.16	1.20	1.21	1.21
7	1.00	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.03	1.02	1.00	1.00	1.12	1.14	1.14	1.13
8	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.02	1.00	1.00	1.00	1.09	1.10	1.09	1.07
9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.06	1.06	1.04	1.02
10	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.04	1.03	1.00	1.00

the figures will fail. For lower frequencies and less loss they average up correctly; at about 10 per cent loss the most reliable results may be obtained. With the wires nearer together, the loss becomes less, until, if side by side, only the resistance loss remains.

General allowance should be made of, say, a power factor of 95 per cent for incandescent lighting and synchronous motors; 85 per cent for induction motors and lighting done together; and for induction motors alone about 80 per cent. The value of p in the previous calculations is the percentage of delivered power lost, not the percentage of loss in the line of the power at the generator end. The potential E is the voltage at the receiving end of the power line.

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A Dollar's Worth of Condensed Information

Locomotive Building

By RALPH E. FLANDERS

PART I
MAIN AND SIDE RODS

Price 25 Cents

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NUMBER 79

LOCOMOTIVE BUILDING

By RALPH E. FLANDERS

PART I

MAIN AND SIDE RODS

CONTENTS

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CHAPTER I

WHEEL AND AXLE WORK

In MACHINERY'S Reference Series No. 79, "Locomotive Building—Part I," were described, step by step, the operations followed in making the main and side rods of a consolidation freight locomotive. In the following the same consecutive method will be followed in describing the machine shop work on the axles, wheels, centers, tires and crankpins, in the Juniata Shops of the Pennsylvania Railroad at Altoona, Pa. The finished product resulting from these operations is shown in Fig. 33, which illustrates the main driving wheels and axle of a new design of exceedingly heavy passenger locomotive, recently built. These are 80-inch wheels, the largest now used in regular pas-

Fig. 1. Raw Material for the Wheel and Axle Work

senger service. The locomotive, being of the Pacific type, requires three driving axles in all.

In Fig. 1 is shown a stock pile of forgings and steel castings in the yard outside the shop, from which the finished work in Fig. 33 is built up. The axles and pins are forged from nickel steel. The tires are made by the circular rolling process, and are received at the shops rough. The wheel centers are steel castings.

The Main Axles—Drilling and Inspecting Holes

Fig. 2 is a drawing of the driving axles of the K-2 Pacific type locomotive, giving the principal dimensions. As shown and as seen also in the axles in the pile at the right of Fig. 1, holes are drilled clear through the axle centers, the diameter of the hole being 2 inches in this case. The purpose of this hole is simply to permit inspection of the

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interior of the forging. If there is a defect in an axle forging anywhere, it may be expected at the center, where seams due to piping and other troubles would surely be found if they were present at all. By examining the interior surface with an electric light mounted on a long rod and provided with a reflector, it is possible to be assured that each one of the thousands of driving axles used on the locomo-

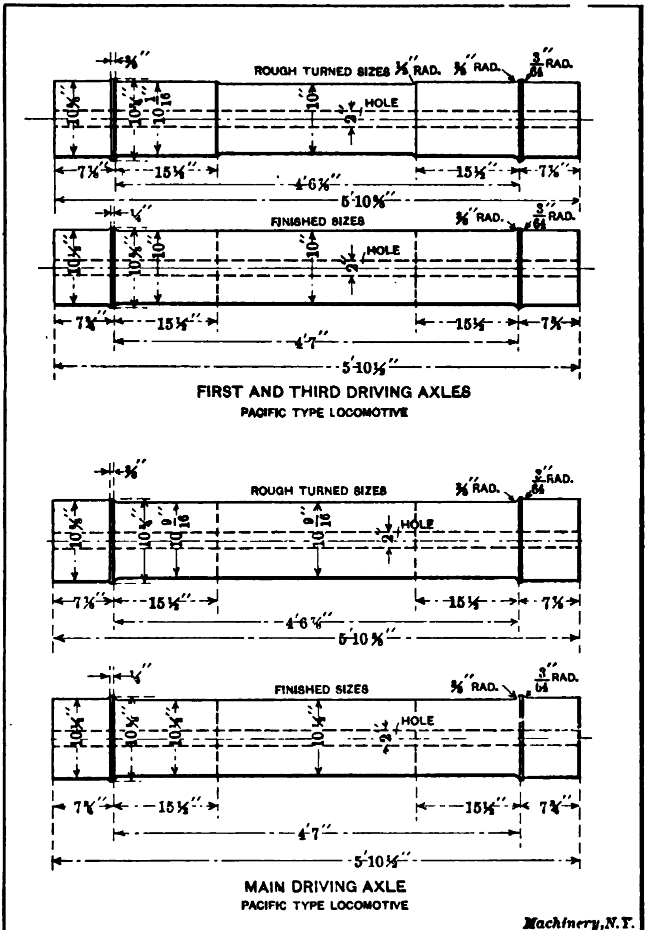

Fig. 2. Rough and Finished Turned Dimensions for Driving Axles

tives of the Pennsylvania system is flawless and homogeneous. This is a form of insurance which is rather expensive, but it is exceedingly effective.

Two forms of axle boring lathes are shown in Figs. 3 and 4, the first of these being the older design. In this machine, as shown, a hollow spindle is used, large enough to take the work in bodily. This

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is grasped by a chuck at the front end, and is centered and supported at the rear end on the points of three set-screws, so that it runs practically true. The drill itself is stationary, being grasped in a clamp bushing on a special carriage. The supporting bushing guides the drill close up to the work, starting it truly and keeping it in line until the end of the operation, thus assisting in keeping the hole concentric. The reason for revolving the work instead of the drill is, of course, that the hole can be kept concentric with the work when this is done. If the work were stationary while the drill only revolved, the chances are that the hole would run away out from the center line of the work, especially if it should meet a flaw or a hard spot in the metal.*

Now while it is necessary to revolve the work, it is evident that this involves constructional difficulties in the lathe itself. The spindle

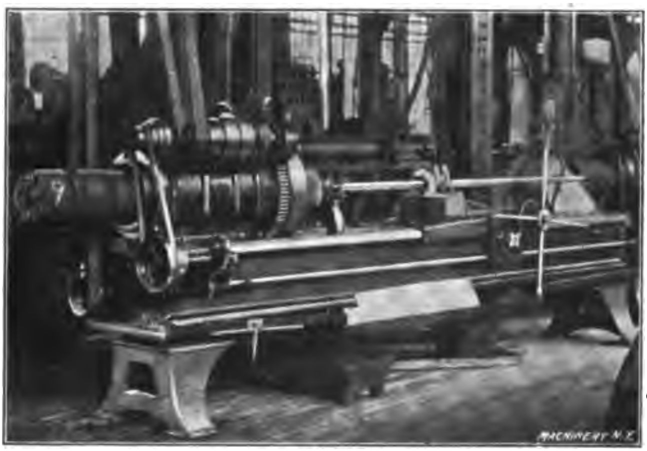

Fig. 3. Drilling the Test Holes in the Axle Forgings

shown in Fig. 3 has to be of a very large diameter, and must be run at very high speed if it is to allow a modern inserted blade drill to operate to the best advantage. To overcome the necessity for revolving a large spindle at high speed, the improved form of axle boring lathe shown in Fig. 4 was developed. Here the spindle is of ordinary proportions, the work being held at one end in the chuck while it is centered and grasped at the other in a revolving holder of the "cat-head" type. This simplifies the problem by reducing the spindle diameter. Still further benefit is derived by revolving the drill itself at a high rate of speed instead of having it stationary as in Fig. 3. The work is also revolved, but all the beneficial results in the way of truing up the hole, can be obtained if the rate of revolution is quite slow. In the case shown, for a two-inch hole, the axle revolves at 15 revolutions per minute, and the drill in the opposite direction, of course, at 75 revolutions per minute.

*See MACHINERY'S Reference Book No 25, "Deep Hole Drilling."

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Fig. 4. An Improved Design of Boring Lathe for Drilling the Axles

Fig. 5. Test Hole under Inspection

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The drill head is clamped to a regular lathe carriage, and is connected for driving the drill with a special splined shaft at the back of the lathe. Unlike the machine shown in Fig. 3, this is practically a regular engine lathe, with only the addition of this splined driving shaft, the drill head on the carriage, the bushing support for the drill, and the revolving rest for the front end of the axle. Otherwise it is provided with lead-screw, change gears, and all the other requirements of the standard engine lathe. It may be used as an engine lathe when the attachments are removed. It is motor-driven, with a controller operated from the carriage.

A well-known type of deep-hole drill is used for this operation. It consists, as shown in Fig. 6, of a long bar *A* of steel, with a slot milled across its front end, in which an inserted blade *B* of high-speed steel is held by means of a taper pin *C*. Square grooves are provided on each side for the escape of the oil and chips. In circular grooves on

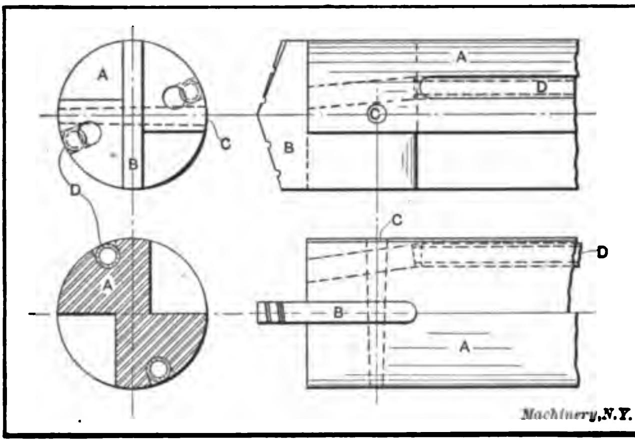

Fig. 6. The Drill used for Deep Boring in the Machines shown in Figs. 3 and 4

the side, tubes *D* are brazed, which lead the oil from the socket in the lathe carriage through to the cutting point. The only part of this drill subject to ordinary wear and replacement, as will be seen, is the steel blade *B*, which is very simple and inexpensive. These lathes, of course, are provided with power pumps, settling tanks, etc., for handling the lubricant, which in this case is a soda-water compound. This is delivered to the carriage by a "trombone pipe" arrangement in the case shown in Fig. 4.

Fig. 5 shows one of the holes drilled and under inspection. For this purpose an electric light is passed in at one end of the bore, provided with a reflector so mounted as to shade the eyes of the inspector from the direct glare of the filament, and still show clearly the walls of the bore, by the reflected light. As these holes have been drilled for inspection and insurance only and are of no further use, they are promptly plugged up again to provide centers for the subsequent

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machining operations on the axles. Various methods of plugging have been tried; but the one which has proved the most satisfactory in the long run at the Juniata Shops is the method which is also the simplest—namely, that of reaming out the ends of the bore with a taper reamer and forcing in corresponding taper plugs in the wheel press. The reamer and the plugs have a taper of ¾ inch per foot. In

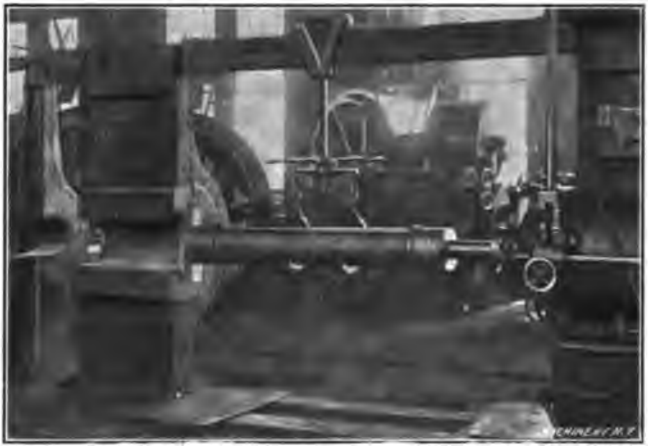

Fig. 7. Forcing Taper Plugs into the Ends of the Bore of the Axle

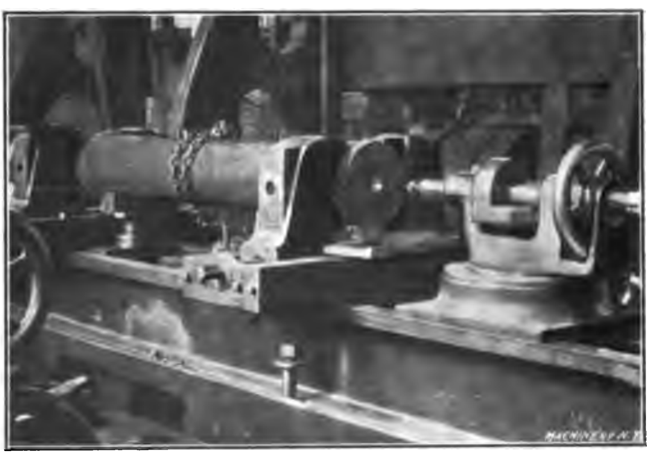

Fig. 8. Centering the Axle Preparatory to Turning

Fig. 7 the plugs are shown being pressed into place; a pressure of approximately 15 tons is used for this operation. The axles are now to all intents and purposes solid, and are treated as such throughout the remaining operations.

The axles are now ready for the turning operations, and the special machinery operations.

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Finishing the Driving Axles

Fig. 8 shows the axle being centered. This is done in a special machine. The two ends are grasped in V-jaws tightened by right- and left-hand screws, which center the axle in front of two drill-spindle heads, one at each end. These heads are driven by bevel gearing from a splined shaft running through the center of the bed, and each is provided with a threaded quill and handwheel for feeding. As usual in centering, a leading hole is first drilled and this is then finished out to a center by the use of the countersink shown. The drift hole provides for rapid changes of drill and countersink.

From the centering machine the axles are taken to the lathe shown in Fig. 9, where the journals and wheel-fits are turned. Templets are used for the lengths of these cuts, one of these templets being shown laid on the wheel-fit at the near end of the axle. Fixed gages are also used for diameters. One of these is shown applied to the

Fig. 9. Turning the Axles

journal, while the other is lying on the top of the carriage. The journals are finished by the rolling operation shown in Fig. 10. The roll is mounted in a forked holder in the tool-post, and fed back and forth across the work under a considerable pressure. There is an opportunity here for the display of judgment by the operator in the matter of the pressure applied. This must be heavy enough to roll down the tool marks and harden the surface. If too great a pressure is applied, however, these results are not obtained; instead, the surface is flaked and disintegrated, leaving it unfit for use in the bearing.

A little kink in estimating the smoothness of a surface is worth mentioning. The instinctive way of doing it is to run the tip of the finger across it to see how it feels. A more delicate test, however, consists of running the edge of the thumb-nail over the surface. For some reason this shows up ridges and irregularities of the surface much more sensitively than does the flesh of the finger tip.

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The axle is now taken to a special milling machine, where the key-seats are cut 90 degrees apart on the ends, the two operations being simultaneous. This machine is shown in Fig. 11. The construction of the machine is plainly evident. The axle is mounted on its centers, and is supported on V-blocks which in connection with the weight of the axle, serve to keep it from moving under the cut. Two sliding

Fig. 10. Finishing the Axle Journals with the Rolling Tool

Fig. 11. Keyseating the Axles on a Special Quartering Milling Machine

cutter heads are provided, with axes at an angle of 90 degrees with each other. This brings the wheels on each side of the engine with the crankpins exactly 90 degrees apart; in other words, it "quarters" the wheels.

The cutters on these spindles have to be accurately centered, of course, if the quartering of the keyways is to be accurate. For this

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Fig. 12. Keyseating the Crankpin in the Horizontal Miller

Fig. 13. Return Crank located in Proper Relation with the Keyseat

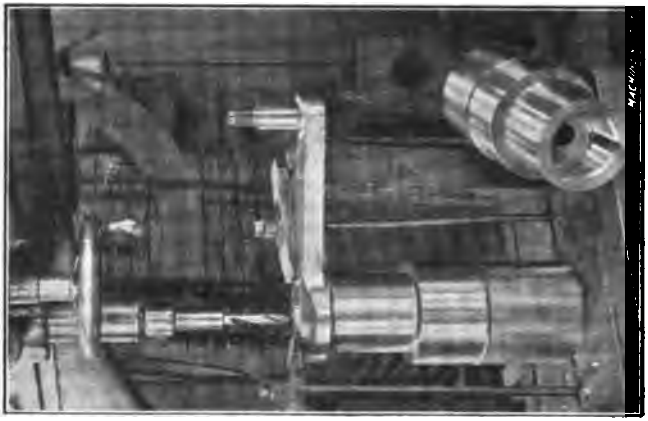

Fig. 14. Drilling the Dowel Holes for Locating the Return Crank

purpose a center line is provided on the back slope of the teeth, half-way between the sides of the cutter. This line on the cutter, in the original construction, was lined up with a pointer set in a stud in a bracket provided for the purpose on the cap of the cutter spindle bearing. The seat for the stud is shown, though the bracket is not in place. This method of centering has been changed somewhat in the practice of the shop. Instead of using this pointer, a reference surface shown at *A* in the engraving is used on the tailstock, and the measurements are made from this to the face of the cutter to set it central. This would seem to be a very satisfactory method, as it would not be affected by wear in the slides and changes in the tightness of the gibbing, owing to the fact that the reference point or surface is directly mounted on the member which supports and centers the work.

After the keyways have been cut on this machine the axle is ready for assembling with the wheel-centers.

Finishing Operations on the Crankpins

The crankpins are machined from the rough forgings by obvious chucking and lathe operations which do not need to be described in detail. With the Walschaerts valve gear, these pins are of two kinds, depending on whether the Walschaerts crank is to be screwed and doweled into a counterbore, as in the case shown in Fig. 14, or is to be keyed and bolted with a split hub, onto a seat turned on the outer end of the pin, as for the case of the K-2 wheel shown in Fig. 33.

The pins shown in Figs. 12, 13, and 14 are of the former sort. Fig. 12 shows the operation of milling the keyseat for the fit of the pin in the main driving wheel center. This keyseat is, of course, required for the main pin only, as this is the pin from which the valve gear connections are made. The other crankpins are forced into place without keying. In Fig. 12 the work is simply held between centers in an ordinary horizontal milling machine, and the keyway is cut with a mill properly centered. At *B* is a key, set into the keyway of a templet mounted just back of the pin; it is used merely to indicate the existence of the templet, which is out of sight. The latter has on it a line corresponding with one scribed on the pin, with which the Walschaerts return crank must match. This templet is used, therefore, in locating the keyway with reference to the line of the crank.

In Fig. 13 the crank has thus been properly located. In Fig. 14 it is shown on the drill press while the three dowel holes which locate it with reference to the pin are being drilled. These holes, as shown, after passing through the flange of the crank, are drilled half into the hub of the crank and half into the counterbore of the pin, locking them firmly together. The crank itself is, of course, held in place by a bolt passing through the center of the pin, and fastened by a nut on the inner face of the wheel.

Boring the Tires

In Fig. 15 is shown a section through the driving wheel rim and tire. The method used on the Pennsylvania R. R. for holding the tire in place is clearly shown. The usual lip or shoulder is provided on

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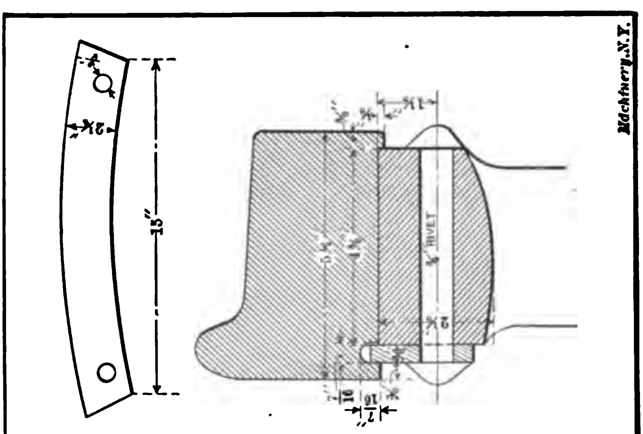

Fig. 15. The Tire and its Retaining Ring

Fig. 16. Boring the Tires Two at a Time in the Wheel Lathe

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the outer edge of the tire for taking the heavy thrust of the rail against the flange of the tire in rounding curves, taking switches at high speed, etc. In addition to this, a groove is turned in the bore of the tire and into this is set a series of plates about 2¼ inches wide and 15 inches long, as shown, held to the inner face of the wheel rim by [illegible]-inch rivets. Six of these plates are ordinarily used, spaced equally around the rim.

This provision for locking the tire in place is made necessary by the tendency which tires have to loosen from the centers under certain conditions. It is a common occurrence to have a tire so heated by the slipping of the wheels on the track in starting at heavy loads, that it will loosen from the center and start to slide off. It cannot, of course, come clear off, as it is retained in place by the flange striking against the rail. The tire is shifted from its position, however, and when it cools again the gage of the engine has been widened, necessitating a cautious trip to the shop for reheating and replacing the tires. By the use of various methods of locking, of which the clip arrangement here shown is one of the most satisfactory, this difficulty is avoided.

The tires are received from the rolling mills rough all over. The finish rolling is, however, accurately and smoothly done. The first operation consists in boring the tire for its fit on the wheel center, and also for forming the retaining lip or shoulder. This operation may be done in either the wheel lathe or the boring mill. In Fig. 16 the tires are being bored in the lathe. They are held on the faceplate by clamps and blocking, and are mounted on parallels to provide clearance for the boring tools when working at the extreme inner edge. The tire is located in place for clamping and is accurately centered by a set of stops with adjustable screw-points, located between each of the four clamps shown. The operations of boring, and of forming the lip, are all of an obvious kind and do not need to be described in detail. An interchangeable blade boring tool is used. The inside diameter is accurately turned to a standard length gage.

Operations on the Wheel Centers

The wheel centers shown in Fig. 17 are of cast steel. Two forms of counterweights are used. One style shown in this figure is cast solid with the wheel centers. This is the style commonly used on passenger wheels of large diameter, where it is possible to get a large enough weight and one far enough from the center to produce the required balancing effect. On freight engines, in general, where the wheel is very much smaller in diameter, it is not usually possible to get into the required space enough weight in cast iron. On this account such counterweights are ordinarily cored hollow, and poured full of lead so as to get the required weight in the required space.

Instead of pouring this into an enclosed space, the Pennsylvania practice is to pour it into open chambers, as shown plainly in the freight wheel in Fig. 20. After these have been poured full, a plate of steel is bolted on for a cover, preventing any possibility of the

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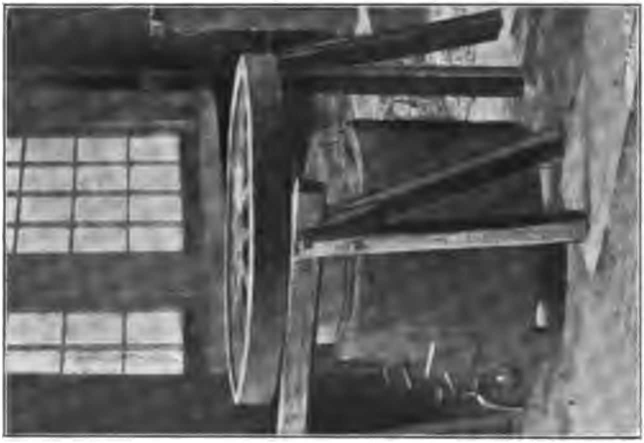

Fig. 18. Pre-heating the Wheel Center while Melting the Bronze for the Hub Liner

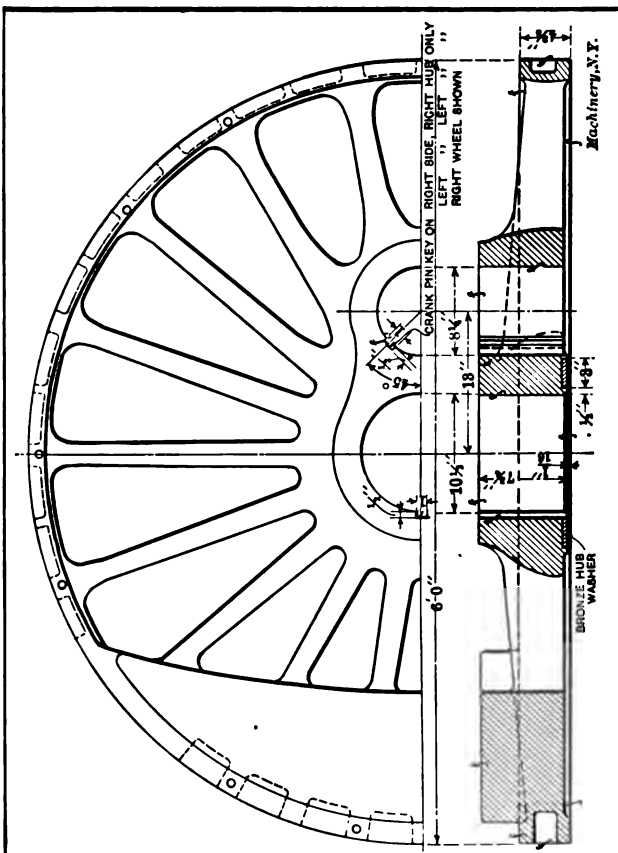

Fig. 17. Center for 80-inch Main Driving Wheel of Pacific Type Locomotive

lead being lost out. The advantage over the closed chamber lies in the fact that in the latter case, the interior is difficult to clean properly and difficult to fill properly; it is common for the lead filling to shake loose and to rattle around as the wheels revolve.

The first operation, if the wheel is to have a hub liner or washer, is the turning of the seat for this with dovetailed grooves to hold

Fig. 19. Boring and Turning the Wheel-center

it in place. This is done on the boring mill. The pouring of a bronze liner that will not crack while it is cooling is an operation that many railroad shops have difficulty with. The method here followed, however, obviates this trouble entirely. The secret of success is shown in Fig. 18, where the wheel-center is seen mounted on horses directly

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over the crucible oil furnace in which the bronze is being melted. The hub of the wheel is not merely warmed, but is heated to a high degree, being somewhere near the point where it would begin to show redness. When the bronze is poured into the heated hub, the liner and the hub shrink together, so that the cracking of the former is entirely obviated. It may be said that the cracking of the liners does no particular harm, it being, in fact, common custom to use them in this condition; but certainly the cracking does them no good, and when it can be avoided by a simple process like this the little extra trouble is worth while.

The wheel-center is now taken to the boring mill, and is first mounted with the inside surface uppermost. Here the periphery and the inside edge of the rim are faced and the hub bored and faced. The wheel is then turned over and mounted as shown in Fig. 19. Here the outside edge of the rim is faced, as is also the hub and its exten-

Fig. 20. The Counterweight Poured into Open Chambers

sion for the crankpin. The center is shown between the two operations in Fig. 20, which also shows very plainly the open form of chambers provided for receiving the counterweight lead in freight locomotive practice.

The particular wheel here illustrated is intended for the electric locomotive on the New York Tunnel service. It will be noted that only the two outside chambers are filled with lead. This particular casting is intended for the rear wheel, in which only the weight of the side-rod is to be balanced. If the same casting were to be used for the main driving wheel, the weight of the connecting-rod from the jack-shaft would also have to be balanced, requiring all the chambers to be filled with lead. This construction permits the use of one casting for both styles of wheels, thus simplifying the question of patterns, and making the castings, in a way, interchangeable.

The hub surface of the axle and crankpin is next marked with chalk,

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as shown in Fig. 21, for scribing the keyways for the axle and the pin. A templet is used for this operation, two forms of which are shown in the engraving. The one in place is for the K-2 or Pacific type locomotive, in which the return crank for the valve gear is located at the proper angle by the keyway of the crankpin. The templet consists of a cross made of rectangular steel, provided with

Fig. 21. Laying out the Keyseat for the Crankpin with Special Templet

Fig. 22. Keyseating in the Slotting Machine with Special Squaring Plate for Setting the Work

gage marks and a circular segment for locating it on the axle bore, and with a disk templet, as shown, for scribing the crankpin bore and marking the keyway. Of the four projections on this disk the two shown nearer the axle are for the keyways, that on one side being used for the right-hand wheel, and the one on the other side for the left-hand wheel.

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For lighter types of locomotives, the crankpin keyway is put directly in line with the axle keyway, both being on the connecting center line. For this condition the templet shown lying against the wheel is used. This is located in the axle bore in the same way, and the crankpin bore is scribed. The long steel bar to which the other members are fastened is the width of the key used in both bores, so this is used for scribing their location. For locomotives using the Stevenson gear, no keyway is required for the crankpin, of course; so only the axle keyway and the crankpin hole are scribed, to insure proper quartering.

When the keyways have been thus laid out, the wheel center is taken to the slotting machine, as shown in Fig. 22, where the keyways are cut to the lines scribed in the previous operation.

For those centers where the keyways are in line with each other and on the center line of the axle and crankpin, great assistance is given in the matter of setting up by the plate shown at *C*. This is

Fig. 23. Pressing the Axle into the First Wheel

fastened to the face of the column of the machine by studs, and is carefully set so that its surface is exactly at right angles to the ways on the bed, on which the work-table is adjusted in and out. By setting a square against this accurate surface, the wheel-center to be machined may be set so that the two keyways exactly square up, and are thus in line with the ways of the machine. When the tool is right for cutting one keyway, the work may be shifted over to cut the other without further setting.

The next operation, not illustrated, is the drilling of the various holes required for the tire retaining plates, the counterweight cover-plate, etc. After this operation, and the pouring of the counterweights, the center is ready to be forced on the axle.

Assembling the Wheels, Axles and Tires

The wheel-press is shown in use in Figs. 23 and 24. The first operation shows the press immediately after the forcing of the axle into the

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first center. The axle is supported from the tie-bar in the usual sling, accurately set for height by means of the screw adjustment shown. The wheel center rests on a roller support, by means of which it may be turned until the keyway exactly lines with the key fitted in the axle.

Fig. 24 shows the second center being forced on. This is also mounted on a roller support for bringing the keyway in line with the key. Blocking is used, as shown, so that the ram applies its pressure to each side of the hub, forcing it down to its seat on the axle, and allowing the end of the latter to project through it slightly if its length is such as to require this.

For a 10-inch wheel-fit like this, the axle is turned approximately 0.010 inch larger than the bore of the hole in the center, the usual rule being about one-thousandth inch allowance per inch diameter of fit. An axle of this size would require anywhere from 120 to 145 tons

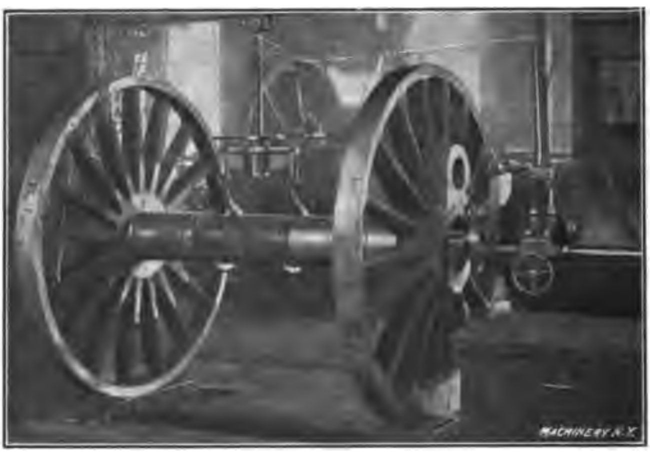

Fig. 24. Pressing the Second Wheel onto the Axle

pressure to force it home, this pressure varying with the character of the machining on the surface fitted and with the exact dimensions to which the parts are finished.

The wheels are now ready to have the tires shrunk on them. Where this tire-shrinking job is done on the wholesale as it is, for instance, at the Altoona repair shops, a heating furnace is used into which the tire is set bodily. In continuous operation this arrangement heats a great number of tires per day. For establishments where the operation is only occasional, the favorite arrangement is to provide a pipe slightly larger in diameter than the tire, and provided with a series of jets through which a gas flame is directed on the tire around its circumference. For the number of tires per day, however, which have to be attended to at the Juniata shops (one locomotive per day is the regular capacity) the arrangement shown in Fig. 25 has been found entirely satisfactory. It provides for heating the tire uniformly

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around its circumference with a single flame, this flame being so arranged as to be capable of accurate control and to give an economical and efficient flame.

As shown in the engraving, the arrangement consists of a turntable on which the tires are mounted, a combustion chamber of sheet iron lined with fire-clay, and a burner in which crude oil is atomized by compressed air at the regular shop service pressure. The combustion chamber is swung on a swivel, as shown, so that it may be directed properly against the work. The burner is supported by it, and is supplied by flexible pipes. The tires are mounted two at a time on the turntable, which is slowly revolved by a push from the operator every once in a while. To determine when the tires have reached the proper heat, an inside solid gage is used, similar to the one used for boring

Fig. 25. Heating the Tires on a Turntable for Shrinking onto the Centers

the tires in Fig. 16, but larger, of course, by the amount of expansion the tire must possess before it can stretch over the wheel-center.

When it has expanded to the point where the gage will enter the bore of the tire in any direction, the tire is picked up by the crane and dropped on the floor of the shop. The crane then picks up the axle with the two centers and drops one of the centers into the tire. The second tire is then picked up and dropped onto the upper wheel-center, the combination being left in the position shown in Fig. 26 until the tires shrink on. The centers and tires rest against the lip on the latter, of course, so that they shrink squarely into position. The chalk mark "H" on the lower tire means that the tire is hot. The correctness of this statement could, without doubt, be determined by experiment.

After the tires have cooled down so that they are firmly shrunk into place, the wheels are taken to the quartering machine shown in Fig. 28, where the crankpin holes are bored. This well-known tool bores the crankpin holes exactly 90 degrees from each other. This is, of

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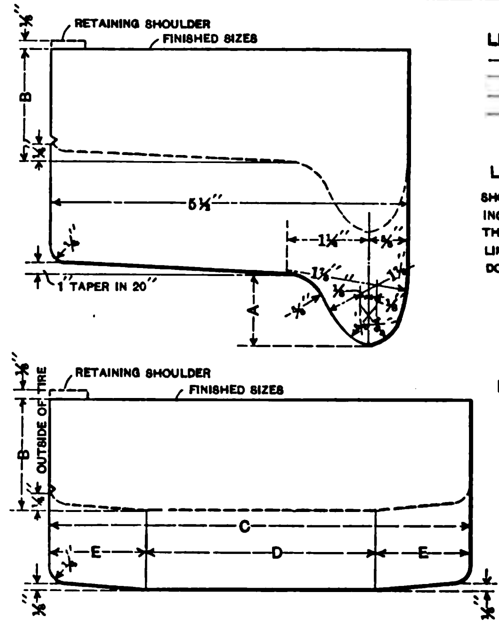
Fig. 26. Shrinking the Tires onto the Centers



LIMITS FOR HEIGHT OF FLANGE=A

	ROAD SERVICE	SHIFTING
ROAD LIMIT	1⅜"	1⅛"
SHOP LIMIT	1⅛"	1"

LIMITS FOR THICKNESS OF TIRE=B

SHOP LIMITS VARY FROM 2 INCHES DOWN TO 1⅛ INCH FOR VARIOUS CLASSES OF ENGINES.
THE ROAD LIMIT IS ⅛ INCH LESS THAN THE SHOP LIMIT FOR EACH CLASS, RANGING FROM 1⅞ INCH DOWN TO 1 INCH

DIMENSIONS FOR VARIOUS WIDTHS OF FLAT TIRES

WIDTH OF TIRE=C	WIDTH OF FLAT=D	WIDTH OF BEVEL=E
5¾"	3¼"	1¼"
6¼"	3¾"	1¼"
7¼"	4¾"	1¼"

Machinery,N.Y.

Fig. 27. Contour of Finished Tire, showing Road and Shop Limits

course, a matter of great importance, for if the various pairs of driving wheels are not all accurately quartered, with crankpins at exactly the same radius, they will cramp and bind in the connecting-rod brasses, until these are distorted or worn loose enough to allow for the inaccuracy. If the quartering machine is accurately made, the wheels may have their crankpin holes bored in them with perfect confidence that they will run properly under the locomotive.

The axle is located by its centers, as in the case of the axle keyseat milling machine shown in Fig. 11. On each end of the bed two heads are mounted, one on one side and one on the other, adjustable for the throw of the crank; each carries a boring spindle as shown. Between the wheels are furnished outboard bearings for the boring-bars, permitting heavy cuts to be taken without vibration or chatter, and without danger of inaccuracy. The rims of the wheels are clamped to this support, as shown, to hold them firmly in position. If the quartering of the keyways in the axle, and the slotting of the keyways in the hubs of the driving wheel, are properly done, the outlines scribed on the crankpin hub at each end can be accurately finished out by this boring operation.

If the wheel cannot be set so that the crankpin holes, as bored by the machine, will finish out to the line on each wheel, it is evident that the keyway on the hole that does not finish out will be out of place, throwing the pin around, and therefore disturbing the relation of the return crank which operates the Walschaerts valve gear. A check is thus furnished for all preceding operations, so far as they refer to the valve gear. It is not expected, and indeed is not found, except in rare cases, that the preceding operations have been at fault, but wherever they have been, notice is served of the difficulty in time to make such corrections as may be required before the engine is assembled. It should be noted that the keyway is filled with a dummy key, approximately flush with the cored hole, before boring the crankpin seat. The operation is not so hard on the tool as it would be for the blade to pass through the open keyway at every revolution.

It will be seen that the quartering machine is arranged so that the boring slides can be mounted on the opposite sides of the heads from that shown, if desired. This makes it possible to quarter wheels in which the right side leads, as well as those in which the left side leads. Engines are now made with the left side leading as standard practice, but some of the older designs, which have to be reckoned with in repair work, call for the right side leading. Provision also has to be made for this in the axle keyseating machine shown in Fig. 11. Here it is not so much trouble to change the machine over, as the milling heads are simply fed along the slides until they have passed each other and are working on the opposite ends of the axle. The feed-screws are long enough to permit this.

Turning the Tires

Another operation, shown already performed in Fig. 30, is the turning of the tires, which is done in the wheel lathe in which the

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Fig. 28. Boring the Crankpin Holes in the Quartering Machine

Fig. 29. Finishing the Ends of a Gang of Crown Brasses in a Double-spindle Milling Machine

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tires were bored, in Fig. 16. All passenger locomotive tires are turned on centers the last thing before the crankpins are forced in place, before the wheels are sent to the erecting floor. On freight locomotives, which do not run at so high a speed and are not so hard on the track, the tires are simply centered very carefully for the boring, finish turning not being required.

The standard contour for driving wheels on the Pennsylvania

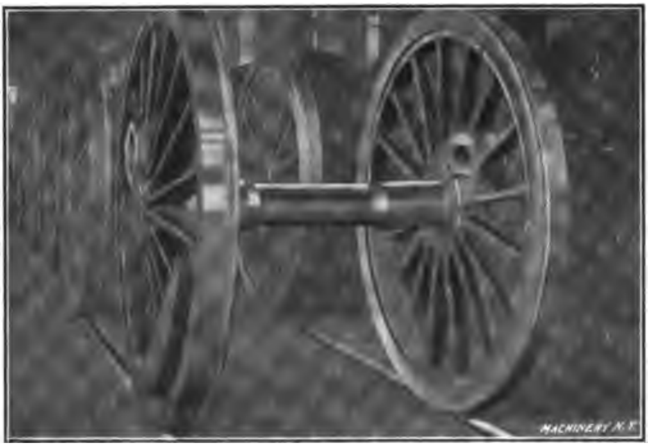

Fig. 30. The Wheels ready for the Crankpins

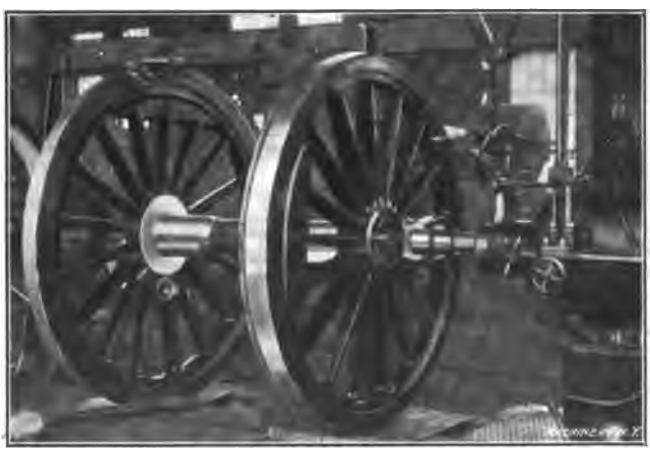

Fig. 31. Forcing in the Crankpins

system is shown in Fig. 27, which also gives details as to the road and shop limits for the height of the flange and the thickness of the rim. Whenever one of the flanges wears down below the road limit given for dimension *A*, the wheels are brought into the shop to be turned off again. When this has been done so often that another

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turning would reduce dimension *B* below that given for the shop limit, the tires are scrapped. Whenever dimension *B*, in service, wears below the road limit given for that dimension, the tire is scrapped. The measurements for determining dimension *B* are taken from the V-groove shown turned in the outer face of the tire, which is ¼ inch below the minimum limit. This groove is cut into the tire in the wheel lathe during the turning operation. Dimensions for flat tires with the various limits are also given in Fig. 27.

Driving the Crankpins and Finishing

Fig. 31 shows the operation of forcing the crankpins into place. In this operation the thrust of the ram against the wheel is taken care of by backing the latter against the "post," which is adjustable to the proper position on the top and bottom tie bars. This gives a solid backing for the pressure required to force the pin in place. About 0.008 inch allowance for driving is made on a crankpin fit

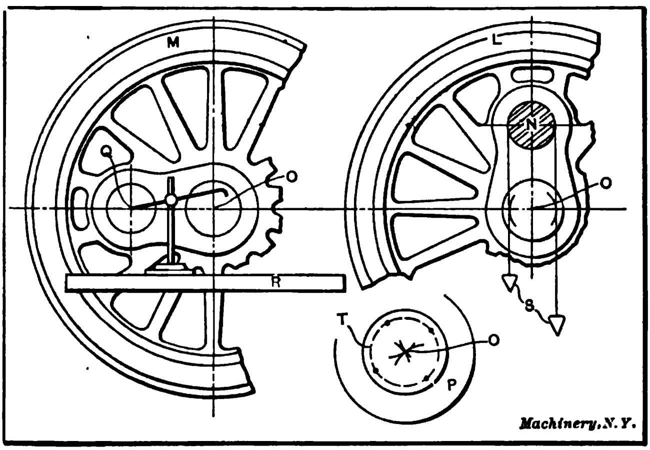

Fig. 32. Method of Testing and Quartering

of 8 inches in diameter, the pressure required ranging from 75 to 100 tons. It may be mentioned in this connection that the driving pressures for all axle and crankpin fits are recorded at the shops, and put on permanent record for use in case of any question arising as to the service of the engine on the road. The engraving shows the second pin being driven, the first having already been forced into place by an identical operation.

It was stated that an accurate quartering machine will take care of the proper boring of the crankpin holes without requiring any anxious thought in this matter on the part of the workman. It is, however, well to know how to test the quartering, so as to make sure that the machine is right in the first place, or to make sure that it does not for any reason wear out of line as time goes on. Fig. 32 shows how this testing is best done. The two wheels on the same axle are shown at *L* and *M*.

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The first thing to do is to set the wheel so that crankpin *N* is exactly vertical over the center of the axle. This is done, as shown, by hanging a double plumb-line over the crankpin and rolling the wheel slightly one way or the other until it is located in position so that the center of the axle *O* is exactly equidistant between the two lines, or until the crankpin circle, struck with the dividers from center *O*, just touches the two plumb-lines equally on each side. Of course, in locating the center *O*, the axle sould be prepared the same as is customary for tramming in setting the valves. For this purpose, the center hole should be pounded full of lead and a new fine center accurately located on it. At the Altoona shops this center is located from a proof circle *T* turned with a sharp pointed tool on each end of the axle, while it is still in the axle lathe as shown in Fig. 9. By striking with the dividers from this proof circle as shown in the

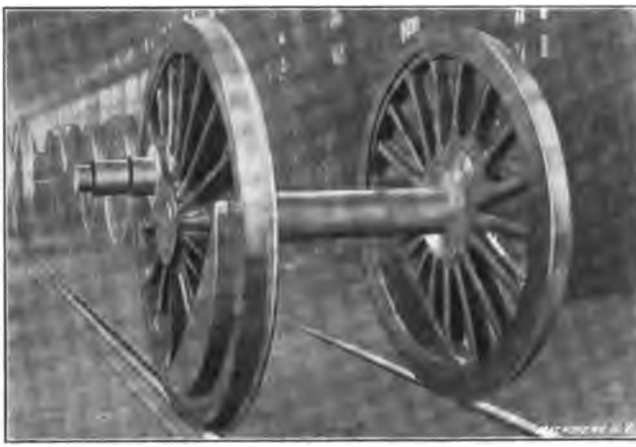

Fig. 33. Completed Driving Axle and Drivers for Heavy Pennsylvania K-2 Type Pacific Passenger Locomotive

detail *P*, the center may be accurately located. Where it is not customary to turn a proof circle on the axle end, a ball point divider is used to scribe the proof line before the center is plugged up. Arcs are struck as shown from this proof circle until they intersect at the center, which is then marked with a prick punch. It is more accurate, however, to turn the proof circle *T* at the time the journals are turned.

Having set one side with the pin exactly vertical over the axle this way, the other side, shown at *M*, should be exactly horizontal with the center. To prove this, first set up a table having a surface-plate *R* mounted on it. With a precision spirit level, the best obtainable, bring this surface-plate to an accurate horizontal position. Then by means of a surface gage, test the center *Q* of the crankpin and *O* of the axle to see if they are the same height. The centers of both the pin and axle on this side should, of course, have been filled with lead and accurately centered in the same way as previously described,

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and as shown at *P*. If the lines on the vertical and horizontal sides have been proved to be correct by this method the wheels are properly quartered and the machine has done its work properly.

It is of great importance that the man in charge of the wheel work should know that the quartering machine is in good condition. If he is sure of this, he can meet with confidence the various reports of inaccuracies and difficulties in this particular that are sure to come to him from engines in actual use. He can meet such "kicks" with calm assurance, knowing that while something is doubtless the matter, it is not the quartering that is at fault.

The wheel, after being painted, is now ready for the assembling floor. The method of construction here described, it will be seen, makes use of the ordinary tools of the railroad shop and represents "good practice." Attention should be called particularly to the fact that fixed gages are used for all the important operations. This relates to the diameters of journals and axle fits, the boring of the tires, the turning of the wheel centers, etc., and besides this, as was explained, the use of the templet method of marking the keyseat and the bore of the crankpin furnishes an automatic check on all of the most important operations of the series.

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CHAPTER II

DRIVING BOX MANUFACTURE

Among the great variety of manufacturing operations to be found in a locomotive building shop, the making of the main bearing boxes is one of those worthy of detailed illustration and description. The operations as laid out in the Juniata shops have proved to be efficient and accurate, but at the same time inexpensive in the matter of the

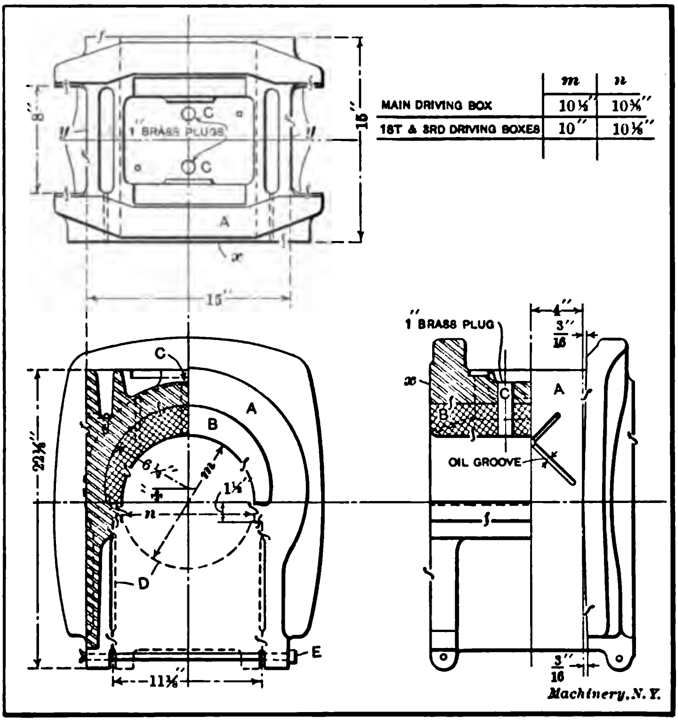

Fig. 34. The Main Driving Boxes for a Heavy Pacific-type Passenger Locomotive

outlay for special tools and special machinery. Only standard machine tools are used on this job, such as find a large range of usefulness in the railroad shop. The number of special appliances is reduced to a minimum. For this reason the lay-out of the operations requires as high a grade of ingenuity as is needed for devising expensive special appliances for rapid manufacturing. In the description, we will begin with the machining of the various separate parts, proceeding therefrom to the assembling and machining of the finished product.

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The Design of the Driving Box

A typical locomotive driving box is shown in Fig. 34. This design is used on an exceedingly heavy Pacific type locomotive. The box is of simple construction, consisting of but two parts, the driving box casting itself, *A*, and the crown brass *B*, which is driven into place in a machined seat where it is pinned by the two brass plugs shown at *CC*. These effectually prevent its loosening under any conditions. The cellar *D*, is indicated by the dotted lines only. The cellar used is a patented device of special construction, whose manufacture is a separate matter from that of the remainder of the box. It is held in place by two pins *E*.

This design of driving box has a plain finished face at *x* for the wheel thrust. The wheel itself has a bronze liner, which forms a suitable surface for contact with the steel casting face at *x*. Some

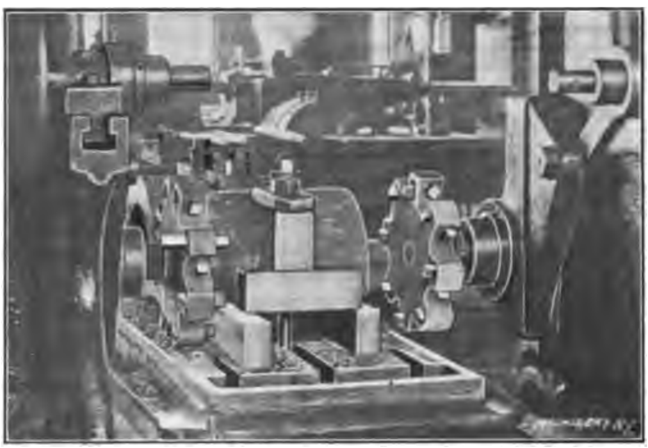

Fig. 35. Enlarged View showing the Two Inserted Tooth Mills

of the boxes shown in the following engravings, however, have a bronze liner inserted in surface *x*. Some of these liners are shown in Figs. 39 to 42. These are used when the hub of the driving wheel is not lined, but is simply faced up true on the steel surface. Still another method of treating surface *x* is to groove it out and pour a babbitt lining, on which a true bearing surface is faced. The standard practice here is to put bronze liners on the boxes, for the reason that it is more difficult to replace a liner on a wheel than on a box. Furthermore, when mounted on the wheel, the liner detracts from the length of the fit between the wheel and axle. This should be noted in connection with Figs. 49 and 50.

Machining the Crown Brasses

The first operation on the crown brasses or bearings, which are made of phosphor-bronze, is shown in Figs. 29 and 35. They are mounted, eight at a time, on long parallels on the bed of a duplex

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milling machine. An ordinary angle-iron serves to take the thrust of the feeding at the end as shown. The castings are held down on the parallels by simple bolts and straps in the central T-slot of the table, each strap spanning the distance from the top surface of one brass to that of the next. The strap of the first brass has, of course, as shown in Fig. 35, to be blocked at the outer end. In setting these up, the parallels are first lined up with the T-slot of the table, to serve as a gage. Then the separate brasses are put in place with the bolts between them, and packed solidly up against one another and against the angle-iron at the end, and set so that all of them project over the parallel the same distance; this leaves about the same amount of metal to be removed from all of them in finishing the ends. As each brass is put in place, care is taken to see that it is at right angles with the face of the parallels, a square being used for the purpose.

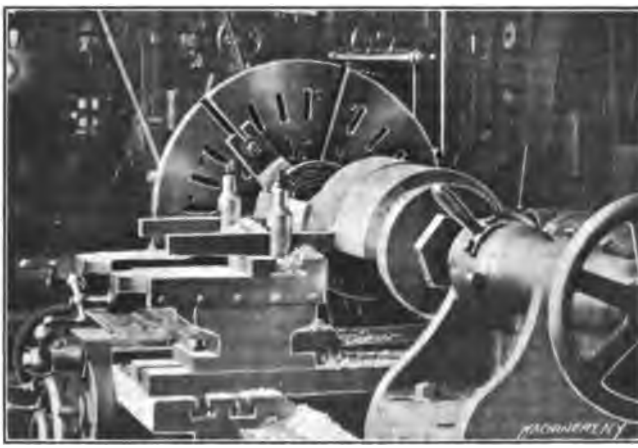

Fig. 36. Turning Two Crown Brasses at once on a Special Arbor

After being properly set and tightened down in this position, the cutter-heads are adjusted to the required distance apart, dividing the chip equally between each end of the work. The cut is then taken across as shown.

The next operation is that of turning the outside diameter of the brasses for the fit in the seat on the main bearing casting. This is done in the engine lathe, as shown in Fig. 36, on a special arbor whose details are shown in Fig. 37, and which permits turning two at a time. The special advantage of this arrangement is that the two brasses are set halfway round from each other on the arbor so that the lathe is cutting all the time. This is not so hard on the lathe as is the case when only one is being turned so that the single tool is "cutting wind" half the time. It also gives more rapid production, as two pieces are cut in practically the same time as one with former appliances.

In Fig. 37, which shows details of the device, the arbor carries a

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fixed flange in the center. The two brasses to be machined are clamped against the opposite faces of this flange by nuts and washers. Each, it will be seen, is thus clamped in place separately, and either member can be loosened without loosening the other. This construction is imperative in the matter of handling these heavy parts and clamping them in place in the lathe without the help of a laborer. The brasses are clamped on their faced ends, and are supported and lined up by means of "cat heads." There are two of these for each brass, and each has three bearing points for the inner surface of the work, set to line up the periphery properly, so that it will finish out when it is bored in place in the main casting.

Originally it was proposed that a special double carriage lathe be provided for this work. All that was found necessary, however, was to mount a supplementary slide on the carriage of an old lathe, and provide this with a second toolpost, as shown in Fig. 36. For this

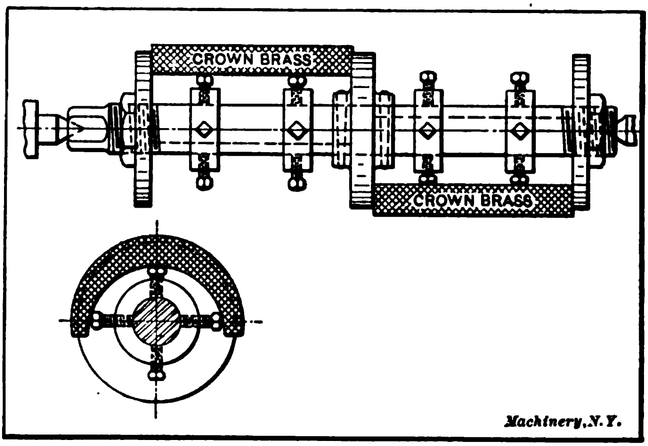

Fig. 37. Details of Special Arbor and Supports used for Turning Crown Brasses

work the arrangement is as satisfactory as a more expensive two-carriage lathe would be. The total time required for taking roughing and finishing cuts on two of these crown brasses is twenty-two minutes.

The final finishing operation on the brasses, before forcing them into the bearings, is that of milling the edges to fit the retaining lips in the bearings. The form is given these edges by means of two formed and relieved milling cutters, as shown in Fig. 38. These are both mounted on the arbor, at the same time, with an overhead support between them to reduce the chattering. A knee-brace is also used, as shown. The work is clamped down to V-blocks, each of which is provided with a hole for the passage of the bolt for clamping them in place, there being a bolt between each adjoining pair of brasses. A gage is provided of the exact contour of the outside and edge of the work, to which the brasses must fit after this cut has been taken.

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Allowance is made in this gage for the extra stock required for the force fit for assembling them in the bearings. The time required for each brass on this milling operation is seven minutes.

Operations on the Bronze Thrust Liner

As previously explained, most driving boxes are provided with bronze thrust liners. The first operation required on these liners

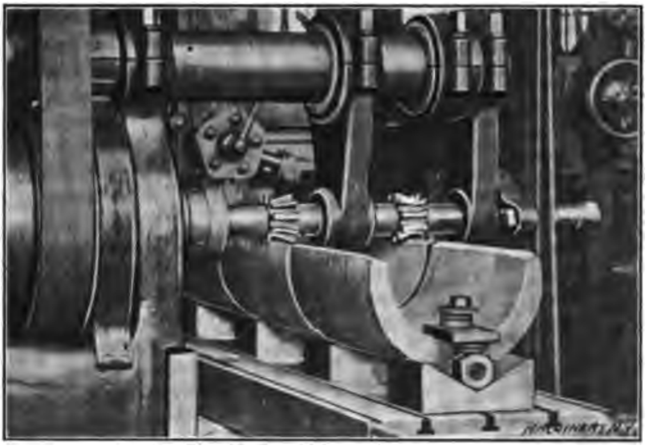

Fig. 38. Milling the Edge of the Crown Brasses for the Fit in the Main Bearing Casting

Fig. 39. Facing the Bronze Liners for the Hub Bearing, on a Faceplate provided with Special Jaws

is shown in Fig. 39. This consists in facing the two sides of the phosphor-bronze liner casting. For this work the faceplate of an old lathe was equipped with the simple appliance shown. These appliances consist of three chuck jaws for gripping the outside of

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Fig. 40. Turning a Stack of Liners on the Boring Mill, after Facing

Fig. 41. Slotting out the Cellar-fit in a Stack of Liners

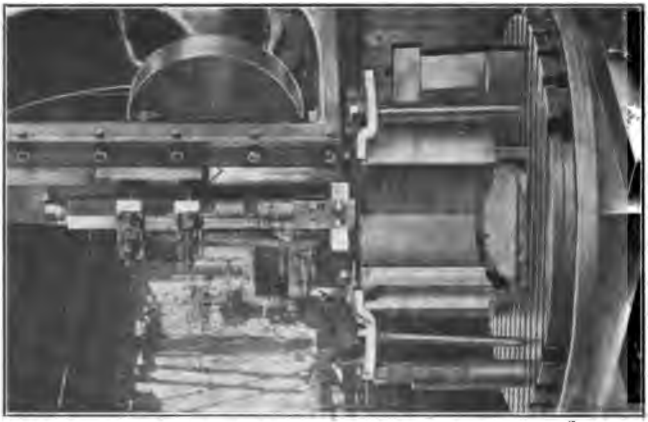

Fig. 42. Machining the Bore of a Stack of Liners on the Slotter

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the casting, an adjustable support or spreader for keeping the ends from springing together (as shown, this is operated by a right- and left-hand screw), and a three-bearing centering support in the inside of the casting, clamped in place by the central nut and washer. These simple devices hold the liner firmly in place for facing off front and back. One chip only is taken on the back side, with one roughing and one finishing chip for the bearing side of the liner.

In Fig. 40, the next operation on the liners (that of turning the outside) is shown. This is done on the table of the boring mill without special fixtures. The boring mill has a great advantage over the lathe, where work is to be done in stacks, as in this case. It is possible to locate the work and clamp it in place without difficulty, as there is no tendency for it to fall off the faceplate onto the floor while it is being set and clamped.

The top liner of this pile has been scribed with a templet to the outline desired. This outline is set so as to run concentric with the tool point, and the pile is squared up on its outside edges to match it, so that they all finish out alike. This operation includes two cuts, one roughing and one finishing.

The next operation consists in machining out the interior outline of the liner. This is also done in multiple, a stack of thirty-two being machined at once in the case shown in Fig. 41. As before, the upper liner has had the desired outline scribed upon it, and the circular interior surface or edge has been centered with the axis of rotation of the work-table, the whole pile being carefully lined up with this upper piece by means of a square, set on the table. The work being thus clamped in place, the jaws and lip are first finished out to the required outline (see Fig. 41), and then, as shown in Fig. 42, the rotary feed is applied, and the inner circle is cut out to the desired radius.

First Operations on the Driving Box

The first operation on the main driving box itself consist in machining out the fit for the crown brass. This operation is done on the circular table of the slotting machine, as shown in Fig. 43. The table having been set so that the tool point gives the proper radius, the work is mounted square with the table, and in a position which permits the interior to be machined out, allowing stock all around as well, as determined by a templet laid on the upper surface. The diameter of the crown brass fit, and the depth of cut at the retaining lips are made to match a templet having the exact contour of the crown brass, with suitable allowance for the force fit.

While set up in the slotter for the operation shown in Fig. 43, the workman scribes a line with the surface gage on the face of the casting on each side, at the same height all around. This line is used for the next operation, shown in Fig. 44, which is that of facing the back of the casting in the boring mill. This is being done in the nearest of the three mills shown. By setting the casting up to the scribed lines, the squareness of the facing with the seat for the crown brass is assured. The bearing is then turned over onto this faced

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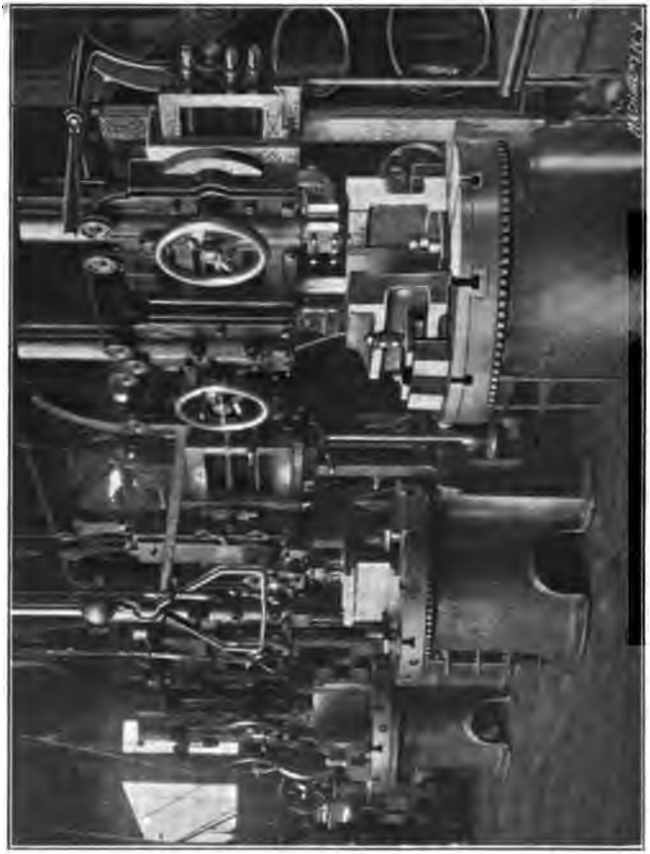

Fig. 44. Facing Operations on the Main Bearing

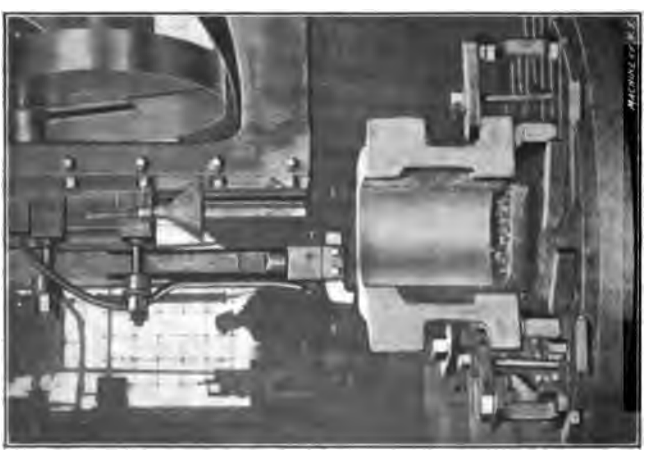

Fig. 43. Machining the Crown Brass Fit

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seat and the outer face with the recess for the liner is machined. Where babbitted thrust surfaces are to be used, this surface is grooved for retaining the babbitt. The total time required for facing both sides, including counterboring and grooving, is two hours.

The work is slotted in this manner before facing, for the reason that the slotting is the vital operation, and the one where there is the greatest liability of not having stock enough to finish out. At the same time the facing, when it is to be counterbored for a bronze liner, must be concentric with the crown brass fit. For this reason it is safest to slot out the fit as the first operation.

Laying-off and Planing the Bearings

The first assembling operation is that of forcing the crown brass into the bearing. This is done under the hydraulic press as shown in Fig. 45. The crown brass is driven in at this time, before the planing operations, for the reason that the pressure of forcing the brass into place springs the bearing casting somewhat, so that it would not be safe to machine it beforehand. The workman consumes about nine minutes per piece in this operation. The castings with the brasses in place are now taken to the laying-off table, where, by means of a templet located by the projecting outside edge of the crown brasses, a line is scribed across the front face of the bearing. This is used in setting up in the operation of planing out the shoe and wedge fits for the frame pedestal.

For this operation, the work is set up on the planer table, as shown in Fig. 46. A large rectangular box casting forming a sort of angle-plate is clamped to the middle of the planer table, with its sides parallel to the ways. To each face of this casting are bolted and strapped six bearing castings as shown. Each of these is shimmed up from the table so that the line scribed in the laying-out operation just mentioned, is parallel with the platen, and at the same distance from the top of the table on all the castings, as shown by the surface gage. When the bearing castings have been set up on each side of the double angle-plate in this way, the grooves for the shoe and wedge fits on each side are planed to the proper width and distance from the front face, and to the proper height from the reference lines scribed by the templet.

The groove for the shoe and wedge fit, of course, is tapered 3/16 inch from each side as shown in Fig. 34, to allow the locomotive frames to rock on the springs without cramping the boxes. To obtain this double taper, each of the bearings is next loosened from position while a parallel shim of the proper thickness is inserted between it and the face of the angle-plate, at what will be the lower end when it is in place on the locomotive. They are then all clamped down again in this position while the planer tools rough out one-half the taper on each side of the slot of each casting. Then the castings are again loosened up while the shim is removed and changed so as to block out the work at what will be the top end of the casting. The work being again clamped down into place, the reverse taper on

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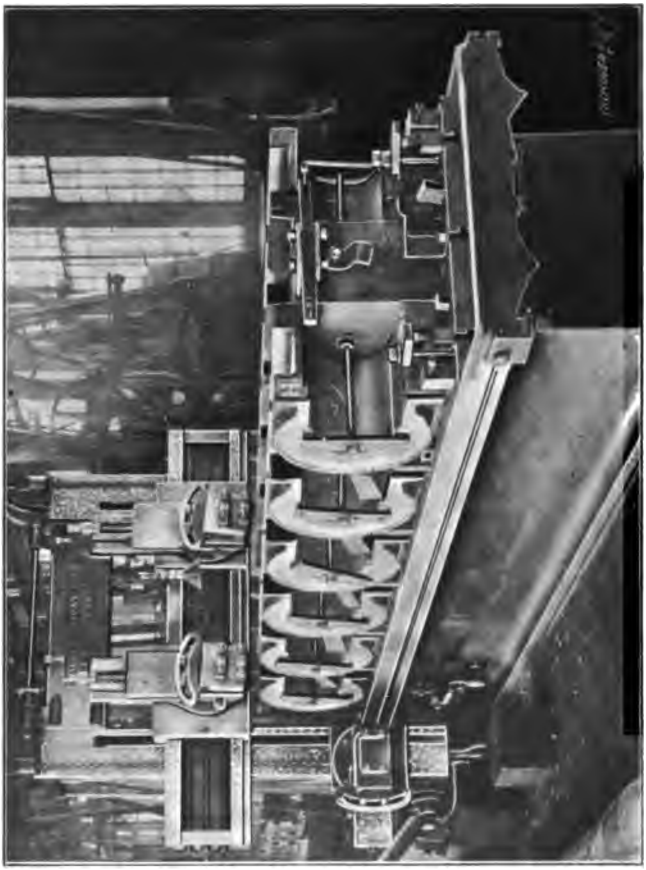

Fig. 46. Planing the Shoe and Wedge Fits in the Main Bearing

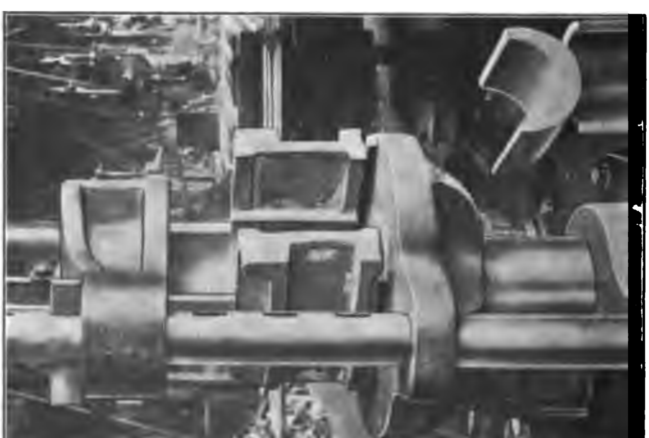

Fig. 45. Forcing the Crown Brass into the Bearing

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each side of each slot is worked out. This finishes the slots on one side.

In the next operation the bearings are all turned over and the shoe and wedge fit slots planed on the other side. In this case there is no packing underneath them, nor elaborate setting to be done, as they are simply clamped against the face of the double angle-plate and are squared up by resting on parallels placed between the finished shoe and wedge fit and the top of the table. As before, the double taper to permit the rocking of the engine on the axles and the springs is effected by shimming out first one edge of the box and then the other, on the double angle-plate. The total time on each bearing casting for planing the shoe and wedge fits, with the tapers for the rocking motion, is about three hours.

Miscellaneous Operations

Each box has now to be laid out accurately for the cellar fit, and for boring the crown brasses. This is done by the use of the templet

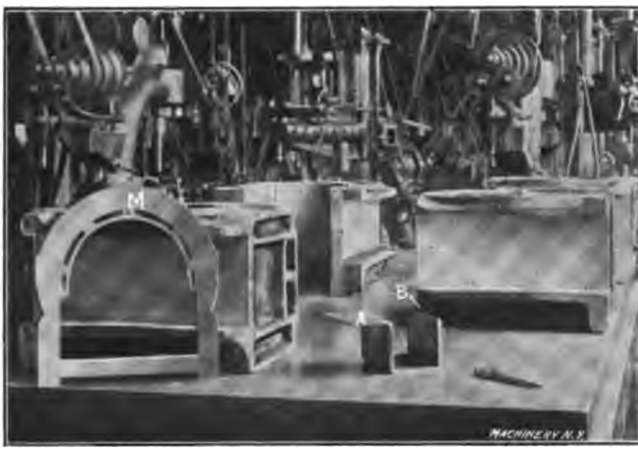

Fig. 47. Laying out the Cellar-fit and Bore on the Bearings

and scratching gage shown in Fig. 47. The face of the scratching gage, shown at *A*, is laid against the bottom of the finished surface of the shoe and wedge fit, while a line is scratched with the scriber along the knife edge *B* on the face of the box liner. Templet *M* is then laid on the face of the casting, and lined up by the mark just scribed. The scriber is again brought into play, and the lines for the bore and for the cellar fit are drawn on the face of the bearing.

In Fig. 48 one of the bearing castings is shown mounted on the table of the slotter for machining the cellar fit. It is mounted on parallels, of course, to allow clearance for the slotting tool. This machining operation simply consists in slotting to the lines scribed by the templet, and to the proper width to fit the cellars. This operaion, on a large bearing, takes about one and one-half hour.

The next operation consists of facing the thrust surface, if babbitt is

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to be used, or in driving the liner into place if a phosphor-bronze surface is desired. This having been done, the face of the bearing is finished off in the boring mill. This is being done in the middle machine of the three shown in Fig. 44, which happens to be at work on an engine truck bearing instead of a main bearing. The time required for this operation is about nine minutes per piece.

A variety of holes for different purposes have to be drilled in the bearing, with its liner, crown brasses and cellar, which is now fitted into place. These various holes (oil holes, bolt holes, dowel holes for retaining lining, etc.), require about three and one-half hours complete. This varies somewhat, depending on whether hard grease or oil lubrication is to be used.

Boring the Boxes

The next and final operation is that of boring out the bearings. This is done in a double-table boring machine, as shown in Figs 49

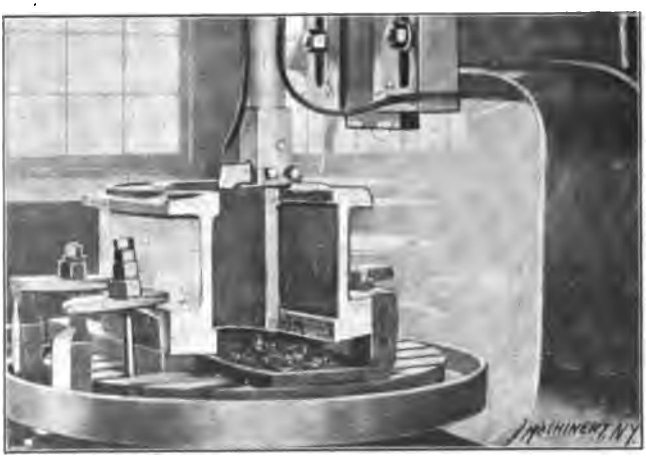

Fig. 48. Machining the Cellar-fit in the Slotter

and 50. It might be asserted, in connection with the opening remarks of this chapter, that this is a special machine. It is so in a sense, as it has a number of special features, consisting principally in the extended length of table used, and in providing two tables instead of one, with an intermediate bushing support. But these features are as applicable and useful in everyday boring practice, where a number of small or medium sized parts have to be handled, as for this particular work; so it is hardly fair to call this a special boring machine for this particular work.

As shown in Fig. 49, four bearings are bored at once, with a multiple blade boring-bar. The tables are long enough so that while this operation is in progress the workman can be removing and replacing four other pieces of work at the other end of the tables. There is thus little or no lost time in the operation of the machine. The workman is kept busy.

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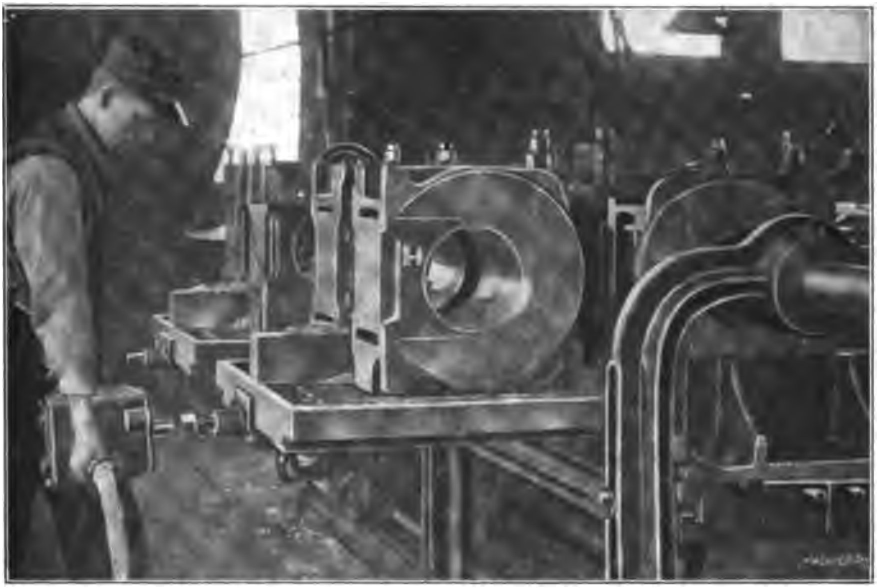

Fig. 49. The Last Operation. Finishing the Bearings on the Boring Machine. Note use of Air Drill for Traversing Double Table

Fig. 50 The Work Completed. Finished Bearings ready for Removal from Boring Machine

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As is also shown in Fig. 50, the work is clamped down onto parallels in the shoe and wedge slots, and it is located as well against parallels extending lengthwise of the tables for squaring up the work with the spindle of the machine. The lines scribed by templet *M* in Fig. 47 are relied on for setting the table of the machine to the proper height in beginning a lot of bearings, and also in adjusting each particular bearing to the proper position on the table. For this, measurements are taken from the end of the table to the scribed line on the face of each bearing, and all are made uniform.

Fig. 49 also shows another ingenious feature—namely, the use of an air drill in traversing the table from one extreme to the other, when changing from a finished to a rough set of castings. This distance is so long as to be tedious, when a change is made by hand. By hitching an air drill to the cross-feed, however, it is shifted very rapidly and easily.

This operation of boring the boxes is performed at the rate of fifty-five minutes per box. This includes rounding the corners of the bearing, as shown, and also the boring out of the cellar to the same radius and the same round. The completed work is shown in the foreground of Fig. 50. This is the last operation. At its conclusion the bearings are ready for assembling in the finished locomotive.

The time given on the various operations takes account of setting up the machine, taking measurements, and all other necessary but "non-productive" periods.

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OUTLINE OF A COURSE IN SHOP AND DRAFTING-ROOM MATHEMATICS, MECHANICS, MACHINE DESIGN AND SHOP PRACTICE

Any intelligent man engaged in mechanical work can acquire a well-rounded mechanical education by using as a guide in his studies the outline of the course in mechanical subjects given below. The course is laid out so as to make it possible for a man of little or no education to go ahead, beginning wherever he finds that his needs begin. The course is made up of units so that it may be followed either from beginning to end; or the reader may choose any specific subject which may be of especial importance to him.

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Reference Series No. 25. DEEP HOLE DRILLING.

Reference Series No. 38. GRINDING AND GRINDING MACHINES.

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