THE SCIENTIFIC PRINCIPLES INVOLVED IN ELECTRIC LIGHTING.

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(Continued from page 294.)

The fundamental principles which underlie all magneto-electric machines are the four great principles discovered by Oersted, in 1819, by Ampère and Arago in 1820, and by Faraday in 1831. In 1819, Oersted discovered the action of a current of electricity on a magnet. In 1820, Ampère discovered the action of magnets and currents on currents of electricity in their neighborhood, and in the same year Arago showed that currents of electricity produced magnetization, thus laying the foundations of electro-magnetism; and, in 1831, Faraday showed that induced currents were produced by the motion of magnets. All machines for the conversion of work into electricity are founded on Faraday's great discovery of the induced current, derived from the relative motion of a magnet and a coil of wire.

Magneto-electric machines are divided into two great classes, according as they furnish continuous currents or alternate currents. All such machines are alternate, as far as regards the currents in the coil; but these currents are made to flow always in the same direction in the external circuit, in continuous current machines, by means of a commutator which reverses the contact at every half-turn.

The machines of Pixii, in 1832, followed by those of Saxton and Clarke, were the first continuous current machines. From these we may pass to Wheatstone's introduction, in 1845, of electro-magnets in place of permanent magnets, to produce the magnetic field. In 1854, Messrs. Werner, Siemens and Halske introduced the Siemens armature, in which the coil is wound longitudinally in a groove. The strength of the continuous current depends on the velocity of rotation, on the length of the wire and on the power of the magnetic field formed by the magnets.

It is remarkable that, in 1854, Hjorth originated an idea which was some thirteen years in advance of his time; he patented an improved magneto-electric battery, in which the currents induced in

the revolving armature pass round the electro-magnets and increase their magnetism, and so increase the induced currents at compound interest rate. This was the celebrated principle afterwards re-discovered by Siemens and by Wheatstone simultaneously in 1867, which has formed the basis of all dynamo-electric machines and which, for equal power, are cheaper and more compact than all other magneto-electric machines.

DYNAMO-ELECTRIC MACHINES.

In February, 1867, Dr. Siemens and Sir Charles Wheatstone, on the same evening, presented to the Royal Society their two papers, "On the Augmentation of the Power of a Magnet by the Reaction Thereon of Currents Induced by the Magnet Itself." According to the principle then put forward by Dr. Siemens, the rotating armature, the electro-magnet and the external resistance, such as an electric lamp, are joined up so as to form one simple circuit. A small amount of magnetism is communicated to the electro-magnet, so that, on rotating the coil, a current is induced alternately in opposite directions, and after being reduced to the same direction by a commutator, this current passes through the coils of the electro-magnet in such a direction as to make it stronger, so enabling it to react on the armature. Thus the magnet and the armature act and react on one another, strengthening the magnetic field and continually strengthening the induced currents. Sir Charles Wheatstone put forward the

FIG. 1.—Dynamo-Electric Machine.

same principle, and called attention to the fact that at the first instant of completing the combined circuit the effects are stronger than they are permanently. The principle of these dynamo-electric machines is clearly shown in the Figure 1, where N and S represent the poles of the electro-magnet enclosing the revolving armature, the external resistance in the circuit being represented by an electric lamp. Sir Charles Wheatstone also pointed out that a very remarkable increase of all the effects is observed when a shunt is employed to divert a great portion of the current from the electro-magnet. By that means, four inches of platinum wire, .0067 in. diameter, was

made to glow. A certain resistance in the shunt was found to be necessary to produce the best effects, so as neither to weaken the magnetism too much nor to give the current too much work to do in heating a high resistance.

In addition to this, Sir Charles Wheatstone showed that the effects above described are far inferior to the effects obtained by placing the work to be done in the shunt circuit. Thus seven inches of wire were made to glow in the shunt, when only four inches of the same wire would glow in the original circuit. There is thus a double advantage, for there is no loss of resistance by introducing the shunt, the resistance of the shunt being the resistance on which the useful work is done.

This improvement, suggested by Sir Charles Wheatstone in 1854,

and now being adopted by Dr. C. W. Siemens in his latest dynamo-electric machines, is very well shown in Figure 2, for which, as well as for the other figures illustrating this lecture, I am indebted to the kindness of the Director of *La Lumière Electrique*.

FIG. 2.—Dynamo-Electric Machine.

Wheatstone also showed that the effects are much less influenced by a resistance in the

electro-magnet branch than in either of the other branches. Thus, with about four inches of glowing platinum wire in circuit, the addition of about five inches of platinum wire in the armature branch, or in the shunt, produced a $\frac{3}{4}$ -inch glow, whilst four feet of the same wire was required in the electro-magnet branch to reduce the glow to three-fourths of an inch. Dr. Siemens has shown that, for the greatest efficiency, the resistance of the rotating coil must be small, but the resistance of the electro-magnet may be increased, and that in both cases the wires should not be small, but of considerable diameter.

THE GRAMME RING.

In the Gramme armature, coils of wire are wound in sections, all in the same direction, round a ring; and each section, when a current is flowing through it, may be regarded as an electro-magnet. The

similar poles of all these sectional electro-magnets will point in the same direction round the ring. Consider only one of these electro-magnets with its north pole directed towards the south pole of another magnet, it will be attracted towards it, and with greater and greater force the nearer it approaches; on passing the south pole, its own south pole will be presented to the south pole of the fixed magnet which it has just passed, and its motion will be continued in the same direction.

Now, suppose no current to be flowing in the ring, then, on applying force to produce the same motion as before, the induced current will be in the opposite direction, *i. e.*, as the coil revolves towards the south pole and past it, the induced current in the coil is round the ring, as we look at it from behind, in the direction opposite to the motion of the hands of a watch.

With right-handed winding of the wire on the ring like a corkscrew, the current is coming towards the observer, or in the opposite direction to the motion of the ring on the side nearest the south pole.

If we consider a section of the ring as it approaches and goes away from the north pole of the magnet, the induced current in the coil, as the observer looks at it from behind, will be in the same direction as the hands of a watch move, so that the current will be away from the observer, or in the same direction as the motion of the ring on the side nearest the north pole. Hence, currents flow opposite ways round the ring, in the two halves of the ring, and meet at points equidistant from the two poles.

DYNAMO-ELECTRIC MACHINES.

When the armature of a dynamo machine is turned, the amount of work which is produced by means of it is proportional to the number of turns of the armature per minute. If the same current passes through the electro-magnet and the armature, then the current in one acting on the current in the other will attract or repel it with a force proportional to the product of two currents, *i. e.*, to the square of the current. The action between the currents is increased four-fold when the current in each is doubled. Hence, when such a machine is used as a generator of an electric current, the external work which can be done by that current in the electric arc or elsewhere is proportional to the square of the current.

USE OF SEPARATE EXCITING MACHINE.

In all dynamo-electric machines, where the same current passes round the magnet and the armature, any disturbance in the resistance of the outer circuit, in the electric arc for instance, at once alters the current, and this alters the strength of the magnetic field, which again produces a further disturbance in the current, so that any disturbance is intensified, just as the permanent magnetism of the iron core is intensified by the action of the current in the machine on itself.

To obtain greater regularity, Wilde, in 1863, proposed to employ a separate continuous current machine to give a permanent magnetic field and to revolve the armature of the second machine between the poles of the magnet which is excited by the first machine. In order to find the yield or effective work of these machines, and their efficiency for electric lighting or for other purposes, we have seen, from the laws of Ohm and Joule, that measurements of current and of the work done by the current must be made.

In the last lecture I indicated four methods of making such measurements, viz. :

1. The galvanometer method.
2. The heat method, *i. e.*, by the change of temperature produced by the current in a wire of given resistance.
3. The electrometer or potentiometer method.
4. The electro-dynamometer method, *i. e.*, by the attraction between different parts of the same current.

EFFICIENCY OF MAGNETIC AND MAGNETO-ELECTRIC MACHINES.

If we take a battery in a closed circuit, we know, from the laws of Faraday, that the amount of current produced is directly proportional to the weights of the chemical elements decomposed in each of the cells of the battery, the quantity of zinc dissolved in the battery being a measure of the quantity of current which has passed. According to the laws of transformation of energy, the work done in the chemical actions is here equivalent to the work done in heating the circuit. We may express the energy or the work done by electric currents in the same way as we express the energy of a head of water by the pressure multiplied by quantity of water. The electro-motive force corresponds to pressure, and the current flowing to the quantity of

water, so that the work done by the current is the product of electro-motive force by the quantity of electricity.

The work which can be done in the circuit is $E_o C_o$, where E_o is the electro-motive force of the battery, and this is spent in heating the resistance. Hence, $E_o C_o = C_o^2 R$, where C_o is the current produced through a resistance R . Now, if any portion of the circuit, carrying a current, be set in motion, under the action of exterior magnetic forces, or under the influence of the mutual reactions of the currents in the fixed and movable parts, then the equivalent to the chemical actions in the battery will be spent in producing the heating of the conductor, and partly in doing the work of the electro-dynamic or magnetic forces. Representing the work done in producing motion by K , and the current in this case by C , we get $E_o C = C^2 R + K$. The work K is equivalent to the external work done by the current C . Now, this external work K gives rise to an opposing electro-motive force in the induced circuit, and the energy of this induced current is $EC = K$; or $E = \frac{K}{C}$ is the electro-motive force due to induction.

The efficiency of an induction machine, when used as a motor, is the ratio of the work K to the total work $K + C^2 R$, i. e., the ratio of the electro-motive force of induction to the total electro-motive force of

the battery. The efficiency $\rho = \frac{E}{E_o} = \frac{K}{K + C^2 R} = \frac{1}{1 + \frac{C^2 R}{K}}$. The effective

work $K = EC$ and $CR = E_o - E$. Therefore, $K = \frac{E \cdot (E_o - E)}{R}$.

If, then, a battery of electro-motive force E_o be employed, and an induction machine be employed as a motor, then the effective work depends on the product of two quantities, one of which increases as fast as the other diminishes.

Now, if one quantity increases as fast as another diminishes, their product is greatest when the two are equal. Hence such a machine is most effective when $E = E_o - E$, i. e., when $E = \frac{1}{2} E_o$, so that $K = C^2 R$ and $\rho = \frac{1}{2}$.

Half the work of the battery is then spent in heating the circuit and the other half in doing the external work. This corresponds to the case where the strength of the battery current is diminished by one-half through the effects of induction. If the same machine be

employed to produce a current of electricity by applying external work to it to turn it, then the energy of the induced current is equal to the work done by the currents during the motion, or $K=EC$. If K is greater than EC at first, then the machine will go faster and faster, and E and C will increase until the product becomes equal to K , when the motion will remain steady. Hence, such a machine should give induction currents of the greatest efficiency when used as a motor.

The above conclusions have been arrived at by considering the attractive and repulsive forces between different parts of a battery current, where the electro-motive force of the battery does not change.

MAGNETIC MACHINES.

The same reasoning will apply to the case where a permanent magnet is used in place of the original battery current, a closed circuit being moved in the magnetic field, or a magnet moved in the neighborhood of a fixed coil. In fact, the theory of Ampère requires that a small closed current should be equivalent to a magnetic molecule, and so a collection of equal small closed currents, all going the same way and occupying a given area, is equivalent to a collection of equal magnetic molecules with their poles in the same direction, *i. e.*, to a magnet. But a collection of equal small closed currents, all going the same way and occupying a given area, is equivalent to a current around that area.

We may readily express the efficiency of magneto-electric machines by a formula. Taking k to be the effective work done by a unit current in one turn of the armature, and n the number of turns per minute, and C the strength of the current, the total effective work is C^2nk , and the work done in overcoming the resistance, R , of the circuit is $R^2E\theta$; hence, by Joule's and Ohm's laws, if C be the electro-motive force, $EC=C^2nk+C^2R$.

Hence, the efficiency = $\frac{C^2nk}{C^2nk+C^2R} = \frac{1}{1+\frac{R}{nk}}$ Thus, for a given

resistance, the greater the number of turns of a machine, the greater is the efficiency, and the higher the resistance, the less the efficiency. This formula shows that machines and lamps of high resistance can only be efficient when the machines are revolving at a high speed.

We may represent the efficiency of batteries or magnetic machines which are employed to drive an electro-motor, such as a dynamo-elec-

tric machine, by a diagram from *La Lumière Electrique*, in which the electro-motive force of the battery or exciting machine is measured on a horizontal line, and either the current or the energy expended is represented by vertical lines. The total electrical energy, represented by a straight line (III), is the sum of the effective work (IV), and the loss of energy by heating, etc. (VI).

It will be seen that when the efficiency is $\frac{1}{2}$, the greatest amount of effective work is produced, and this amount of work is one-half the total electrical energy. Since the electro-motive force is proportional to the number of revolutions a minute, this diagram gives the effective work and efficiency at different speeds.

In the case where the fixed and the movable parts of the machine are electro-magnets, and the same current passes round both, then we have—

(1.) The action of the currents on one another.

(2.) The action of the fixed magnetic core on the movable coil, and of the movable magnetic core on the fixed coil.

(3.) The action of the two magnetic cores on one another. Hence, the value of k is of the form of $a+bm+cm^2$, where a, b, c are constants, and m depends on the magnetic properties of the cores.

Each of these actions arises from the influence of two equal currents on one another, and, therefore, will be proportional to the square of the current and to the number of turns of the coil in a minute, so that K is proportional to $nC^2(a+bm+cm^2)$ and the efficiency

$$\rho = \frac{1}{1+c_2R} = 1 + \frac{1}{R} \frac{1}{n(a+bm+cm^2)}.$$

The most important part of the action in such machines depends on the action of the two magnetic cores one upon another. The reactions between the fixed and the movable cores produces great disturbance, in consequence of the cores not taking up their full magnetism

FIG. 3.

- I. Electro-motive force.
- II. Strength of current.
- III. Energy converted into electricity.
- IV. Effective work in the external circuit.
- V. The efficiency.
- VI. Energy not converted into useful work.

instantly, but requiring time for their full magnetization. In consequence of this, in all dynamo-electric machines, it is necessary to allow the rotation to go on, through an angle determined by the retardation of the magnetism of the cores, before taking away the current from the machine to do external work; hence, in order to get the greatest current, the springs for making contact must in such cases be shifted round in the direction in which the rotation is taking place. Faraday attributed this retardation to the time required to develop the molecular currents in the molecules of the magnet.

ALTERNATE-CURRENT MAGNETO MACHINES.

In alternate-current machines, there is no commutator for making the current continuous; but the currents from the coil are collected and sent through the external resistance in opposite directions for every half-turn of the armature. The earliest of these was the "Alliance" magneto-electric machine, which has been adopted by the French government for lighthouse illumination. Holmes converted this into a continuous current machine, and was the first to produce, in 1858, the electric light on a grand scale for lighthouse illumination. He afterwards removed the commutator and again converted it into an alternate-current machine.

The four methods of placing the coils on the revolving wheel, in machines for electric lighting, which have been employed in light-houses, have been summed up by Mr. Douglass:

1. In Holmes' magneto-electric machine, the bobbins are arranged transversely, with their axes parallel to the axis of rotation around the circumference at the wheel.

2. In Siemens' machines, the wires are lengthwise and revolve about the long axis of the piece on which they are wound.

3. In Gramme's machines, the wires form a helix around a ring.

4. In the De Meritens machines, the wires are wound as in the Gramme, but are divided into separate parts which are insulated from one another and, passing in succession in front of opposite poles of magnets, give off alternate currents.

THE SIEMENS ALTERNATE-CURRENT MACHINE.

A central disk carrying bobbins is set at right angles to a shaft and revolves between two sets of electro-magnets ranged in circles on each side of the disk, having their axes parallel to the shaft. The bobbins

have no iron cores, and so the heating caused by magnetization and demagnetization of the iron is avoided. The electro-magnets are excited by a small Siemens continuous-current machine.

This is similar to Wilde's dynamo-electric machine, which he produced in 1866, except that in the coils on his cast-iron disk Wilde placed soft iron cores and arranged them so as to form eight groups of four each. The current from one of these groups excites the electro-magnets, whilst the other seven groups give out the current for external use. Among the more recent alternate-current machines, arranged so as to be excited by a separate continuous-current machine, there is one which has lately been invented by M. Gramme, in which the bobbin of the continuous-current machine, which excites the magnets, is placed on the same axis with the rotating armature which gave the alternate currents, so that the two turn with the same velocity and the combined machines run at the same rate. This is much simpler than having two machines, and it is called a self-acting machine.

From principles which I have already explained, the greatest amount of effective work or yield obtained from an alternate-current machine, driven by a separate exciter, is not more than 50 per cent. of the electrical work given out by the first machine.

RESULT OF MM. MASCART AND JAMIN'S EXPERIMENTS.

M. Jamin has found that, in the Alliance machine for electric light and giving alternate currents, the strength of current can be calculated by Ohm's law, considering the electro-motive force as proportional to the velocity, but replacing the resistance of the bobbins by a resistance about eight times as great. The resistance to be added is proportional to the velocity of the machine.

All theoretical determinations of the efficiency of machines are complicated by the retardation of magnetization of the magnets, which necessitates a change of position of the commutator in the direction of the rotation of the armature. If this change were not made, then it would be possible, with a bobbin in which the wire resistance was high, to get currents in opposite directions when the coil is rotated at different rates. For slow rotation, the galvanometer needle is deviated to one side; on increasing the velocity of rotation, the current is increased, at last reaches a maximum, and beyond that diminishes rapidly to nothing and becomes negative; as the velocity

is still increased the current reaches its greatest negative value, and then increases again, and may have several such fluctuations.

The efficiency of the Siemens dynamo-electric machines has been examined experimentally by Dr. C. W. Siemens, who has communicated the results of his investigations to the Royal Society, and by Dr. Hopkinson, whose results are published in the *Transactions of the Institution of Mechanical Engineers*; also M. Hospitalier and Messrs. Auerbach and Meyer have experimented on Gramme machines, and MM. Mascart and Angot have considered the subject, both theoretically and practically, in some excellent papers which have been given in the *Journal de Physique*.

Taking the experiments of M. Hospitalier, as given in *La Lumière Electrique*, we get the results, as shown in the diagram :

	Ohms.
The total resistance of the machine before the experiment was	1.185
“ “ of the heated bobbin	.75
“ “ of the heated electro-magnet,	.72
Total,	1.47

FIG. 4.

- I. Electromotive force.
- II. Strength of current.
- III. Energy converted into electricity.
- IV. Useful work in the external circuit.
- V. Efficiency.

The resistances are laid down on the horizontal line to the scale of 1 c.m. per ohm.

The scale of electro-motive force (I) is 1 c.m. for 10 volts.

The scale for currents (II) is 1 c.m. for 10 webers.

The scale for work (III and IV) is 1 c.m. for 20 kilogrammetres.

Curve V represents the efficiency, *i. e.*, the ratio of the effective work in the outer circuit to the total work converted into electricity.

This curve expresses the ratio of the external work to the total work produced, and approaches

the value unity as the resistance is increased; but for high resistances very little work is produced. From the curves it would appear that this Gramme machine does most effective work in the outer current,

without greatly heating the internal circuit, when the total resistance is about 4 ohms, *i. e.*, when the external resistance is about twice as great as the internal resistance. For less resistances the machine is greatly heated from the amount of internal work consumed, and for higher resistances the work converted into electricity becomes very small. The following numbers give the results of one experiment with the dynamo machine :

Number of turns a minute,	1000
External resistance,	2.7 ohms
Current,	25.5 webers
Electro-motive power,	107 volts
Total work converted into electricity,	3.64 h. p.
Effective work in external circuit,	2.38 h. p.
The efficiency in this case is 65 per cent. The effective work in the outer circuit is not more than 50 per cent. of the total work done to produce it.	

(To be continued.)

Cometary Spectra.—Thollon has presented to the French Academy an account of some comparative observations upon the spectra of the two recent comets. In the first the continuous spectrum predominated, and finally it almost obscured the band spectrum. In the second the three carbon bands were very well defined and very brilliant, but gradually fading upon the side of the violet, and he was not able to observe any slight traces of a continuous spectrum until the night of the 21st of August. The brilliancy of the head and tail varies rapidly with the distance from the sun. In the absence of any precise photometric measurements the variations seemed to be nearly in the inverse ratio of the square of the distance. If this law should hold rigorously it would probably follow that the white light of comets is almost entirely due to reflection of the sunlight. It seems hard to reconcile the slowness with which the brilliancy of the band spectrum varies with the common opinion that the elements of a comet are raised to incandescence by the sun's heat. Comets, like nebulae, may have some heat and light of their own, independent of that which may come from solar, mechanical and electric action.—*Comptes Rendus.* C.