

system at a great distance from the machine, and with a remarkably small loss, and this is of especial advantage where several lights have to be employed, because if there are as many long conductors as there are lamps, then the whole of the loss of current due to the resistance of the cables must be borne by each lamp, whereas if a number of lights can be included in a single circuit, the loss of current from the resistance of conducting cables is equally divided among all the lamps in the series. There are, of course, commercial advantages in burning a number of lights in a single circuit from one machine, for there must necessarily be an enormous increase in prime cost in the adoption of a number of dynamo-electric machines in the place of one, as well as in the multiplication of conducting cables, and the advantage in point of attendance and repairs is obviously in favor of the single machine system.

With respect to the advantage of being able to operate a number of lights at a considerable distance from the machine, it is an interesting fact that the sixteen lights which are now in regular use for the illumination of Charing Cross terminus are actuated by a machine working in the Anglo-American Company's works in Lambeth, and that within a few weeks a large area of the City of London will be illuminated by the same system by forty lamps, all operated in one circuit by a machine working in the Lambeth works.—*Engineering.*

## THE BRUSH SYSTEM OF ELECTRIC LIGHTING.

By CHARLES F. BRUSH, M. E.

### PECULIAR FEATURES OF THE DYNAMO-ELECTRIC MACHINE.

The most prominent peculiarities of the Brush dynamo-electric machine are embodied in the armature, the arrangement of field magnets, and the commutator.

The armature consists of a flat ring of soft cast iron, revolving in its own plane. This ring is composed of two or more parts, each provided with a series of grooves, and insulated from each other, all in such a manner as effectually to prevent the induction of currents in the iron itself when it is revolved in a magnetic field. On this ring are wound eight bobbins of armature conductor, whose planes radiate from the axis of rotation.

The field magnets of the machine face both sides of the armature, in the plane of its rotation; thus both sides of the flat bobbins of armature conductor are exposed to the direct inductive influence of the magnets. This arrangement of armature and magnets differs radically from that adopted in the Gramme machine, the only other dynamo-electric machine of note in which an annular armature is employed.

Field magnets of opposite polarity are applied to diametrically opposite points of the annular armature, which then consists practically of two semicircular magnets, having their like poles joined. Each of these semicircular armature magnets, if straightened out, would be much longer than its own diameter, and would have its bobbins wound at right angles to its axis, and covering the greater part of its length. Now it will be evident, that with a given length and weight of armature conductor, a very much greater number of convolutions may be formed on such an armature than would be possible on other armatures whose length from pole to pole is short compared with their diameter. But inasmuch as the field magnets are applied to both sides, and very nearly the whole length of the long armature, the magnetic field in which the bobbins of conductor move is quite as intense as that obtainable when any other form of armature is employed, and perhaps more so; hence the electro-motive force of current obtainable with an armature conductor of given resistance is, *ceteris paribus*, very much greater with this form of armature than with any other. For a practical demonstration of this let us consider the brush machine known as size number 7. In this machine the resistance of the armature conductor, measured through the brushes on the commutator (the resistance is the same in all positions of the commutator), is about four ohms; in some machines a trifle more, in others a trifle less, according to the purity of the copper wire employed. When the armature is rotated at its normal speed of seven hundred and fifty revolutions per minute, in its normal magnetic field, the electro-motive force developed in its conductor is sufficient to maintain its normal volume of current through an external resistance, including the field magnets of the machine, of fully eighty ohms; or through a resistance twenty times as great as its own. No other form of dynamo-electric machine has yet shown a result comparable with this.

This current operates from sixteen to eighteen powerful electric lights arranged in a single circuit, giving to each an arc of about two millimeters length. The resistance of these arcs averages about four and a half ohms each, as shown by many careful measurements of different lamps, both singly and in groups. (The measurements included the magnet helix of each lamp, the resistance of which is, however, quite small, and will be given further on.)

The bobbins of wire on the armature of the Brush machine are not connected together in a single circuit, but each pair of diametrically opposite bobbins only, are connected together. The two free ends of the conductor thus formed of each pair of bobbins are carried to the commutator and attached to diametrically opposite segments thereon, which segments are not connected with any other bobbins. Thus each pair of bobbins is entirely independent of any other pair.

In this arrangement, which secures important advantages, the Brush machine again differs radically from the Gramme, and all similar continuous current machines.

The commutator consists of four separate rings of metal, each ring consisting of two nearly semicircular segments, whose ends, on one side, are separated by a considerable space. This space is occupied by a piece of metal attached to an adjoining ring, and known as an "insulator." It is insulated by an air space from each of the segments between whose ends it is located, the other ends of the segments being simply separated by a single air space. The office of the "insulator" is to separate either of the brushes which collect the currents from the commutator, from both segments during a certain interval, and twice in each revolution of the commutator. During these separations, the two bobbins of wire on the armature which are connected with the pair of segments, are not only out of the general circuit, but are open circuited themselves, so that no current can circulate in them.

Each pair of bobbins on the armature is thus provided with a commutator ring, and the segments of this ring occupy the same angular position with regard to other segments that its bobbins occupy with regard to bobbins attached to the said other segments.

It will now be seen that only one pair of armature bobbins is out of the general circuit at one time; and this is made to occur when the said bobbins are at and near the neutral points of the armature, and are not in a condition to contribute

to the general current. Now, if it were not for the "insulators" above described, the idle bobbins would afford an easy passage for the current from the active bobbins, and thus destroy the efficiency of the apparatus.

The Gramme form of commutator, which is employed for the production of continuous currents in all machines other than the Brush form of commutator is free. The principal difficulty arising from the use of the former is this: The bobbins of wire, when at and near the neutral points of the armature, contribute little or no useful effect; but the current from the other bobbins must pass through them in order to reach the brushes, thus experiencing a considerable and entirely useless resistance, and, owing to the opposite directions of the currents through the active bobbins on opposite sides of the neutral points, these currents, by passing through the idle bobbins, tend strongly to produce "consequent" points in the armature where the neutral points should be; thus interfering seriously with the proper distribution of the armature's magnetism.

It may be argued that the evil above indicated is eliminated by allowing each of the brushes to embrace several sections of the commutator, corresponding to bobbins on both sides of each neutral point; this is, no doubt, true to some extent, but another and perhaps worse evil is thus introduced; the bobbins corresponding to the commutator sections embraced by each brush are short circuited in themselves, through the brush, and, owing to their comparatively small resistance, powerful currents are developed in them. These currents absorb much motive power in their production, and rapidly heat the bobbins.

Again, during each revolution of the Gramme commutator, each brush must break and make again as many contacts as there are sections of the former, and each act involves the whole current; while with the Brush commutator, only two contacts and breaks occur with each brush in each revolution, and these successively in the different rings, so that but one-fourth of the whole current is involved at one time.

Further, the use of oil for lubrication, appears to be impracticable with the Gramme form of commutator, while it may always be employed on the Brush commutator with great advantage. Thus the durability of this commutator is made immensely greater than that of the other.

When necessary, the wearing segments of the commutator may be replaced by duplicate pieces in a very few minutes by any mechanic.

### PECULIAR FEATURES OF THE LAMPS.

These are—very great simplicity of construction: insuring ease of management, safety against internal derangement, and securing great regularity of working; the double magnet circuit conveying currents of opposite direction, by means of which any number of lamps may be operated in a single circuit without any irregularity of action; the short circuiting safety attachment, by which any lamp offering an abnormally great resistance, owing to the final consumption of its carbons, or other cause, will, without any change of strength in the main current, automatically short-circuit the said lamp, and thus preserve the integrity of the general circuit; the multiple sets of carbons, burning successively, without the intervention of any switching or other special mechanism, and yet securing the maintenance of the light for any desirable length of time without requiring attention; lastly, the absence of any adjustment to be made by the attendant other than placing the carbons.

These lamps contain no clockwork or similar mechanism of any kind. The movement of the upper carbon, actuated by gravity, is controlled by a simple annular clamp which surrounds the rod carrying the carbon. When the lamp is in operation, one side of this clamp is lifted by magnetic action; this causes it to grasp and raise the rod, and thus separate the carbons. As the carbons burn away, the magnetic action diminishes, and the clamp and rod move gradually downward, maintaining only a proper separation of the carbons; but when the tilted annular clamp finally touches the supporting floor from which it started, any further downward move will at once release the rod and allow it to slide through the clamp, until the latter is again brought into action by the increased magnetism due to the shortened arc between the carbons. In continued operation, the normal position of the clamp is in contact with its lower support, the office of the controlling magnet being to regulate the sliding of the rod through it. If, however, the rod accidentally slides too far, it will instantly and automatically be raised again, as at first, and the carbon points thus maintained in proper relation to each other.

Each magnet helix is first wound with a few layers of coarse wire, through which the main portion of the current operating the lamp passes. Over this coarse wire is wound a very much greater length of fine wire, having its ends connected with the terminals of the lamp, but in such a manner that the electric current shall pass through it in a direction opposite to that in the coarse wire helix. Thus the fine wire forms a secondary circuit of high resistance through the lamp, which circuit is independent of the arc between the carbons, and is always closed. It follows from the difference in direction of the current in the two helices, that the fine wire helix will constantly tend to neutralize the magnetism produced by the coarse wire or principal helix. The number of convolutions of the fine wire helix and its resistance are so proportioned to the number of convolutions in the principal helix, and its resistance together with that of the normal voltaic arc, that the magnetizing power of the latter shall be much greater than that of the former. Notwithstanding the small amount of current which passes through the fine wire helix (about one per cent. of the whole current) its magnetic power is very considerable, owing to its great number of convolutions.

Now, when a number of regulators provided with these double helices are operated in a single circuit, great uniformity of action will be maintained owing to the peculiar function of the secondary helix. Thus, when any lamp gains more than its normal arc, the resistance of its main circuit is thereby increased; more current is consequently shunted through its secondary helix, and the resultant magnetism is diminished, allowing the carbons to approach. On the other hand, if an arc becomes too short, its resistance is reduced, and less current is shunted through the corresponding secondary helix; consequently the working magnetism in that lamp is increased and its carbons are drawn further apart. Thus it will be seen that, although the general strength of the current operating a large number of these lamps does not vary, each lamp performs its regulating functions through the agency of varying magnetism, precisely as though it were the only lamp being operated.

In practice, the resistance of the fine-wire helix or helices in each lamp is rather more than four hundred and fifty ohms; while the resistance of the coarse wire, various connections, carbons, and voltaic arc, in each lamp used with

the sixteen-light machine, is about four and a half ohms. Hence not more than one per cent. of the whole current is diverted from the arc. The resistance of the coarse-wire helix, carbons (copper-coated), connections, etc., in each lamp is very small. To determine this resistance, sixteen lamps were connected in series in the usual manner, about two hundred feet of No. 10 copper circuit wire being used. Full-length carbons were then placed in the lamps, and the upper and lower carbons of each lamp were connected by means of a strip of sheet copper wired to each carbon. The resistance of the whole set was then measured, and found to be 2.10 ohms, showing a resistance for each lamp, with its carbons, of 0.131 ohm. This is 2.91 per cent. of the whole resistance of the lamp when in operation. To this loss must be added the one per cent. due to that amount of current diverted from the arc by the fine-wire regulating helix, making a total loss of 3.91 per cent. The remaining 96.09 per cent. of the whole energy absorbed in each lamp appears in the arc between its carbons.

The shunting or short-circuiting device in each lamp consists of a small magnet core, surrounded by a coarse and a fine wire helix, similar to those of the working magnet. No current passes through the coarse wire until the magnet which it surrounds has raised its armature. The latter, together with the coarse wire, then form a part of the short circuit established through the lamp. The fine-wire helix of the shunt is put in the circuit of the fine-wire regulating helices before described. During the normal operation of the lamp this fine-wire helix exercises a magnetizing influence on its inclosed core, which thus attracts its armature with a certain degree of force, but not enough to lift it. But when, through the exhaustion of the carbons in the lamp, or from their failing properly to feed together, the arc between them becomes considerably lengthened, thus developing an abnormally great resistance in the lamp, a greatly increased current will be shunted through the fine-wire helix, the iron core of the latter will raise its armature, and thus establish a circuit of low resistance through the lamp, independent of its carbons.

Evidently, when the short circuit is closed as above, very little current circulates in the fine-wire helix, and the magnet would drop its armature and thus open the circuit, were the armature not retained by some means other than the magnetism due to this helix; but it will be remembered that the coarse-wire helix surrounding the same iron core is now brought into action, and by this means the armature is retained.

This simple cut-out mechanism effectually guards against all the dangers of general extinction, which are always present when many lamps are burned in a single circuit. It will be noticed that it operates without any change in the strength of the general current operating a system of many lamps; and herein lies its great merit. No effect is produced in any lamp other than the faulty one, except a slight increase of brilliancy after the "cut-out" of the latter has acted. The extinction of a lamp necessarily calls attention to it at once, and the renewal of its carbons may be effected in a few seconds. As soon as the renewed carbons come into contact, a considerable portion of the current through the lamp is diverted from the magnet of the cut-out device by the passage afforded through the carbons; thus the retaining magnet is so weakened that it drops its armature and restores the whole current to the carbons, and the light is re-established.

The carbons employed in these lamps are covered with a thin coating of copper, and are twelve inches long. They burn without renewal about eight hours, during which time about nine and a half inches of the positive and four inches of the negative are consumed.

When it becomes desirable to operate the lamps more than eight hours continuously, "double-rod" lamps are used. In each of these lamps two movable rods and two sets of carbons are employed. The rods are placed three inches apart, and each is moved and controlled in the manner already described. But both rods are actuated by a single magnet, the same as that employed in the single-rod lamp. The simple lifting mechanism connected with the magnet is so arranged that one of the rods is lifted slightly in advance of the other. Now, when the electric current first passes through such a lamp, the two sets of carbons, having their members in contact, will divide the current between them; but as soon as the members of one set are separated by the action of the magnet, the whole current is thrown through the other set without showing any spark between the members of the set first separated. When the continued action of the magnet separates the remaining pair of carbons the voltaic arc appears, and the light is established. It must now be evident that the clamp, which was the last to raise its rod, will be the first to release it when a forward movement of the carbons becomes necessary. Hence, the set of carbons which first commenced to burn will continue to do so until consumed, the other set remaining separated as at first. But when the burning carbons are exhausted and can no longer move forward, any further effort of the magnet to feed them will at once bring the reserve set of carbons into contact; the whole current will then pass through this set, leaving the other carbons without current and permanently separated. The reserve set of carbons will now be separated by the magnet and burn continuously. In practice, the transfer of the voltaic arc from one set of carbons to the other is accomplished instantaneously, and is scarcely noticeable.

It will be seen that this simple arrangement cannot possibly fail in its function, there being no switch to get out of order or contact surfaces to become burned; further, that it is perfectly automatic, and operates at the instant a change becomes necessary, and not sooner.

By means of these double-rod lamps a system of lights may be maintained in continuous operation sixteen hours without requiring any attention. This is sufficient for the longest winter night. But by introducing three rods and three sets of carbons in each lamp the lights may be maintained quite as easily and certainly for twenty-four hours. In this case the clamps lift their rods successively and feed them in the reverse order, as before.

A notable feature of the Brush lamp is the absence of any adjustment requiring the attention of the user; he has but to insert the carbons, and the lamps are always ready for action.

### RESULTS ATTAINED.

On August 22, 23, and 25, 1879, a system of very careful measurements, both electrical and dynamic, were made by thoroughly competent persons for the purpose of accurately determining the efficiency of the Brush machine and lamps. These measurements were made at the works of the Telegraph Supply Company, Cleveland. The machine used was of the size known as No. 7, its individual mark, distinguishing it from other machines of the same class, being "Y." This

machine differed in no respect from others of the same size, and there is no reason to suppose that its performance was above or below the average. Sixteen lamps of the usual pattern were employed, with about two hundred feet of copper line wire No. 10.

The machine was driven by a "Buckeye" engine, with automatic cut-off, running at a speed of 157 revolutions per minute. This gave to the machine an average speed, during all of the experiments, of 770 revolutions per minute. The normal speed of these machines is 750 revolutions per minute, at which speed they operate sixteen lamps normally, giving to each an arc of about two millimeters length. At the speed at which these measurements were made the sixteen arcs were perceptibly lengthened, and, of course, more than the normal amount of driving power was required. But as this produces a nearly corresponding increase of current, no attempt was made to bring the speed nearer to the normal point, because of the difficulty of changing the speed of the engine.

The machine being entirely new, the bearings heated considerably. Some driving power must have been wasted on this account.

The first electrical measurements made were for the purpose of determining the difference of potential existing at the terminals of each lamp. This was done by a method devised by the writer. A battery of 48 small Daniell's cells was constructed on the "gravity" plan, carefully insulated, and freshly charged with sulphates of copper and zinc to insure normal action. The sixteen lamps having been adjusted to furnish arcs as nearly equal as possible, the positive terminal of one lamp was connected with the positive terminal of the battery; while the negative terminal of the same lamp was connected with the negative end of the battery, a very sensitive galvanometer being interposed. Now, it is evident that, if the difference of potential between the ends of the battery is greater than that between the terminals of the lamp, current will circulate in its normal direction through the battery, and will be indicated by the galvanometer; but if this potential is less than that of the lamp, current will also flow through the battery, but in a reverse direction, and will also be indicated by the galvanometer; while if the potential is the same in both, no current will pass in either direction through the battery, and the galvanometer will show no deflection.

As was expected, the potential of the battery proved to be higher than that of the lamp. By means of a simple arrangement any number of the battery cells could be included in the circuit at pleasure. Such a number was chosen that the galvanometer indicated no current, or currents fluctuating from zero, equally in both directions. The appearance of the arc in the lamp was then carefully noted and the speed of the machine counted. From time to time the condition of the arc would change slightly, or the speed of the machine would vary a little, and then more or less battery would be necessary to effect the balance. When such changes occurred, another set of observations was made as before, and so on, until results corresponding to the average working of the lamp were secured. The large number of observations made sufficiently eliminated the error due to the fact that no fraction of a single cell of the battery could be used in the experiments. This method of measuring the difference of potential between the terminals of the lamp proved to be extremely satisfactory and certain in its operation; the addition or subtraction of a single cell of battery being sufficient to deflect the galvanometer needle strongly to the right or left.

A series of observations was thus made on each of eleven of the sixteen lamps, selected at random, and as the results obtained from the various lamps agreed very closely, it was deemed unnecessary to carry the process further.

The difference of potential between the terminals of the average lamp was thus found to be equal to that of 42.46 cells of the battery, at an average speed in the machine of 770 revolutions per minute.

The next point to be determined was the resistance of the average lamp. For this purpose a resistance, consisting of coils of coarse copper wire, was substituted for one of the lamps, and made of such amount that 42 cells of the battery exactly balanced the difference of potential between the two ends of the resistance, while the speed of the machine was 770. This resistance wire weighed nearly seven hundred pounds, and was but slightly warmed during the experiment. Its resistance was then immediately measured with much care before any appreciable cooling could take place, and was found to be 4.56 ohms. From this resistance, balancing 42 cells of the battery, the resistance of the average lamp, corresponding to 42.46 cells of battery, is easily deduced, and is found to be 4.56 ohms. This, multiplied by sixteen, the number of lamps in circuit, gives the total resistance of the lamp circuit—72.96 ohms. The resistance of the conducting wires between the machine and lamps was not measured, being so small as to be unimportant. The average total internal resistance of the machine, measured through the brushes, with the commutators in various positions, and all of the conductors warm from active use, was found by careful measurement to be 10.55 ohms. Variations of only about 0.02 ohm were observed when the commutator was turned in different positions. This resistance, added to that of the lamps, gives a total normal internal and external resistance of 83.51 ohms, 87.36 per cent. of which (72.96 ohms) is external. Hence, 87.36 per cent. of the current developed by this machine is available for external work.

We have found that the electro-motive force of the current, overcoming a resistance of 4.56 ohms (the resistance of one lamp), is equal to that of 42.46 cells of battery; hence the total electro-motive force of the current, overcoming the total resistance, is

$$\frac{42.46 \times 83.51}{4.56} = 777.59 \text{ cells.}$$

Assuming the electro-motive force of each cell of battery to be 1.079 volts, the electro-motive force is  $777.59 \times 1.079 = 839.02$  volts. By Ohm's well-known formula, the current in circulation is

$$\frac{839.02}{83.51} = 10.04 \text{ webers.}$$

We have next to determine what portion of the energy of the whole current was utilized in the sixteen voltaic arcs for the development of heat and light. To this end the resistance of the sixteen lamps, including all connections, magnet wires, carbons, etc., minus the resistance of the arcs, was determined in the manner already described, and found to be 2.1 ohms. This, subtracted from the total resistance of the lamps, 72.96 ohms, leaves 70.86 ohms as the resistance of the sixteen arcs. This is 84.85 per cent. of the resistance of the entire circuit; and as the work performed by the current in any part of the circuit is directly as the resistance of the said part, it would appear that 84.85 per cent. of the en-

ergy of the current was expended in the arcs. But this is not the case, because 1 per cent. of the current passing through each lamp is diverted from the arc by the fine-wire adjusting helices, as before explained. Deducting 1 per cent. of 84.85, we have left 84, expressing the percentage of the entire energy of the current appearing as heat and light in the arcs.

The electrical measurements above described were made in the presence and with the assistance of Mr. G. H. Wadsworth, Chief Operator and Electrician of the Western Union Telegraph Co.'s Cleveland office.

The instruments used in measuring resistances were a tangent galvanometer by Phelps, and a set of standard resistance coils rating from 0.01 ohm upward. The measurements were made by substitution.

During the progress of the electrical measurements above described, a system of careful measurements of the driving power absorbed by the machine was also made. This was done by Mr. Isaac V. Holmes, of Cleveland, a gentleman widely known as a mechanical engineer and expert. His measurements were made from indicator diagrams taken at the cylinder of the engine, and covered a period of about three hours.

The following table embodies the results obtained by Mr. Holmes:

Total power developed with the 16 light machine at 770 revolutions "closed".....	18.73 H. P.
Less friction load of engine "light".....	2.44 "
" " due to increase of load (18.73—2.44=16.29) at 5 per cent.....	0.81 "
Total power absorbed by 16 light machine at 770 revolutions "closed".....	15.48 "
Total power developed with the 16 light machine at 770 revolutions "open".....	4.23 H. P.
Less friction load of engine "light".....	2.44 "
" " due to increase of load (4.23—2.44=1.79) at 5 per cent.....	0.09 "
Total power absorbed by 16 light machine at 770 revolutions "open".....	1.70 "
Total power absorbed by 16 light machine at 770 revolutions, in the production of current (15.48—1.70).....	13.78 "

NOTE.—The terms "closed" and "open" refer to the external circuit of the machine. Thus, when the machine was "closed," its current was working through the normal external resistance—that of the sixteen lamps. When "open," no current was generated.

These results agree very well with those obtained by other engineers with other machines of the same size and style. On February 6, 1879, Mr. Noah R. Harlow, of the Lowell Water Power Co., measured the power absorbed by one of these sixteen light machines located in the Merrimac Print Works, Lowell, Mass. The speed of the machine averaged about 747 revolutions per minute while operating sixteen normal lights, and the total power absorbed under these circumstances was found to be 13.86 horse-power, including friction of dynamometer employed.

On March 18, 1879, another machine was measured at the dry goods depot of John Wanamaker, Philadelphia, Pa., by Wm. Lee Church, of the Buckeye Engine Co., of New York. Mr. Church employed the method of indicator diagrams, and obtained as a result 13.5 horse-power for the total power absorbed by the machine when operating sixteen lights. The speed of the machine was not given in his report, but was presumably about 750 revolutions per minute, as he was aware that this was the speed at which the machine should be run.

The higher results obtained by Mr. Holmes may be attributed to the increased speed at which his machine was driven, and the abnormal friction at the journal bearings, due to their newness.

Referring to the electrical measurements already described, we find that we have a current of 10.04 webers, with a total resistance of 83.51 ohms. Now, the value in foot pounds of any current is  $C^2 R \times 0.737335$ ; wherein C is the current in webers, R the total resistance of the circuit in ohms, t the time in seconds, and 0.737335 the equivalent in foot pounds of one weber per ohm per second. Hence, the value in foot pounds per minute of the current from the sixteen light machine is:  $10.04^2 \times 83.51 \times 60 \times 0.737335 = 372410.58$ . This, divided by 33,000=11,285, which is the energy of the current expressed in horse power. Again,

$$\frac{11.285}{15.48} = 0.729;$$

hence, 72.9 per cent. of the total power applied at the pulley of the machine was converted into current. We have already found that 84 per cent. of the entire energy of the current appeared in the voltaic arcs. Multiplying 72.9 by 0.84, we have 61.24 as the percentage of the total driving power appearing in the arcs.

If we deduct friction and resistance of air from the gross power absorbed, and consider only the power actually absorbed in the production of current, as is usually done in determining the efficiency of dynamo-electric machines, we have

$$\frac{11.285}{13.78} = 0.8189;$$

or 81.89 per cent. of the absorbed power converted into current. As before, 84 per cent. of this current appearing in the arcs, we have  $81.89 \times 0.84 = 68.79$  per cent. of the entire power absorbed in the production of current, present as heat and light in the sixteen arcs.

#### RECAPITULATION.

Resistance of dynamo-electric machine.....	10.55 ohms.
" " external circuit.....	72.96 "
Total resistance of circuit.....	83.51 "
Resistance of 16 voltaic arcs.....	70.86 "
Percentage of current available for external work.....	87.36 "
Percentage of current appearing as heat and light in 16 voltaic arcs.....	84.00 "
Electro-motive force of current.....	839.02 volts.
Volume of current.....	10.04 webers.
Total driving power required.....	15.48 H. P.
Driving power absorbed in production of current.....	13.78 "
Energy of current expressed in horse-power, Percentage of gross power converted into current.....	11.285 "
Percentage of absorbed power converted into current.....	72.90 "
Percentage of gross power appearing in arcs, Percentage of absorbed power appearing in arcs.....	81.89 "
	61.24 "
	68.79 "

These results require no comment. Their excellence is apparent. They have not yet been approached by those of any other dynamo-electric apparatus operating multiple lights; or even by those operating single lights.

Mr. Louis Schwendler, in his excellent "Report on the Results obtained by the Electric Light Experiments," dated London, Nov. 1, 1878, gives the percentage of absorbed power appearing in the electric lamp, in the cases of four dynamo-electric machines. The lowest result given was 30, and the highest 62 per cent., the latter with a machine of the Siemens type. This is much the highest efficiency we have yet seen reported authentically of any dynamo-electric machine. The result was obtained only under the most favorable circumstances, as pointed out by Mr. Schwendler, viz.: with a machine furnishing a single light, and developing a large volume of current (29.5 webers) of comparatively low electro-motive force.

The Brush machine, developing a much smaller volume of current, of a vastly greater electro-motive force, and operating sixteen lights, yet shows a much higher efficiency, viz. 68.79 per cent.

From the peculiar nature of the Brush system of lighting, arise very important advantages over other systems, not yet touched upon. We refer to the great ease with which the lights may be operated a long distance from the dynamo-electric machine, and the small loss of effect occasioned by so doing.

When a separate dynamo-electric machine is employed for each light, according to the systems which appear to be most in favor in England and France, or when the same machine furnishes several currents, each operating a light, then each lamp must be independently connected with the machine, and the whole loss of current occasioned by the resistance of the pair of conducting wires must fall upon each single lamp. There must also be as many complete sets of conductors as there are lamps.

In the Brush system, one pair of conductors is sufficient for all the lamps, no matter what their number may be; and the loss due to these conductors falls not on each lamp, but is equally divided between all. Hence, in order to reduce the loss in each light due to the conductors in the single light system to the same amount as that in each light in the multiple light system, the size of the conductors in the former case must be to that of the conductors in the latter case, directly as the number of lights operated in the multiple light system to unity. And, since the single light system requires as many sets of conductors as there are lamps, while the multiple light system requires but one set of conductors, the total weight of conductors required for a given number of lamps (keeping the total loss of effect due to this cause the same in both systems) is as one, for the multiple light system to the square of the number of lamps for the single light system. To illustrate: Suppose sixteen lights are operated at a given distance from the dynamo-electric machine or machines, and the loss of current due to resistance of conductors is limited to a certain amount, and let the weight of conductors required in the multiple light system be represented by 1, then the weight of conductors required in the single light system will be  $16^2=256$ . Hence, in operating a large number of lights at a long distance from the source of power by the single light system, either an enormously expensive system of conductors must be employed, or else a great part of the whole energy of the currents will be wasted in overcoming the resistance of the smaller conductors.

This objection to the single light system is fatal when any considerable separation of the machines and lamps becomes necessary.

The Brush system of lighting being free from this defect, the lights may be maintained at a great distance from the source of power with very little loss of effect, and by means of conductors of moderate size and cost. The resistance of number 10 (Stubs gauge) copper wire of commercial purity, is about 0.6 ohm per thousand feet; therefore 7,600 feet of such a conductor will equal in resistance only one of the sixteen lamps already described:

$$\frac{4.56}{0.6} \times 1,000 = 7,600,$$

so that fifteen lamps of full power could be operated through such a conductor of this length; or the whole sixteen with a loss of only about 6 per cent. in effect. Only 50 per cent. of the total effect would be sacrificed by working through such a conductor more than eleven miles in length (60,800 feet), and this loss might be reduced one-half by doubling the size of the conductor, which would still be of moderate dimensions.

No reference has yet been made to the use of more than sixteen lamps in the circuit of the No. 7 machine; but 17 or 18 lamps are often employed with the machine running at its normal speed of 750 revolutions per minute, and with good effect, although the total light produced is less than with sixteen lamps. At the speed at which the above described measurements were made, viz., 770 revolutions, nineteen or twenty lamps may be burned with tolerably good effect, although the maximum amount of light is obtained with sixteen.

As many as thirty-three lamps have been operated simultaneously in the circuit of a No. 7 machine running at a speed of 800 revolutions per minute, with an arc of appreciable length in each lamp, but the total light produced was less than half that obtained when sixteen or seventeen lamps were employed. When the number of lamps operated by the No. 7 machine, running at full speed, is reduced below sixteen, the brilliancy of the remaining lights is of course increased, but not in proportion to the reduction in number. Hence the total amount of light is diminished. The quantity and intensity of the current are such as to produce the maximum light in sixteen arcs.

At the time Mr. Holmes measured the power required to drive the sixteen-light machine, he also measured that required by a six-light machine of the size and style known as "No. 5."

This machine furnished six beautiful lights in single circuit, similar to those of the No. 7 machine, but with somewhat shorter arcs. (It will be remembered that the No. 7 machine was driven above its normal rate of speed.) The total power required to drive this machine was 4.5 horse power. The following are Mr. Holmes's figures:

Total power developed with the 6-light machine at 922 revolutions "closed".....	7.18 H. P.
Less friction load of engine "light".....	2.44 "
" " due to increase of load (7.18—2.44=4.74) at 5 per cent.....	0.24 "
Total power required by 6-light machine.....	4.50 "

No measurements of the current from this machine were made.

## REMARKS.

Much has been written by eminent electricians and others about the enormous loss of total lighting effect which follows the use of more than one center of light in an electric circuit. Some state that the total light diminishes as the square of the number of lights increases; others that the loss is as the cube of the number of lights.

These extraordinary assertions are made without any reference to the energy or character of the current employed, and are never supported by any experimental data.

The experience of the writer has uniformly shown that when a small amount of electrical energy is expended at several points, very little or no light results; while if the same energy be properly expended at one point, a large amount of light may be evolved. On the other hand, when a large amount of current energy is properly expended at a number of points not too great, the total light produced may nearly equal that evolved when the whole energy is concentrated at one point.

A certain amount of energy is required before any light at all is produced, and if the division falls below this point, nothing in the way of light results. But after a certain point is reached, at which a good light is produced, then the increase of light appears to be almost directly as the increase of energy exhibited in the arc, the length of the latter remaining constant. Mr. Schwendler's experience here appears to coincide with our own. In his report, before mentioned, he says: "If we make the highly probable supposition that the resistance of an arc of constant length is inversely proportional to the current which passes through, then the light produced would be proportional to the current. This appears to be the case." Again he says: "Although the light must be very nearly proportional to the total energy consumed in the arc, the resistance of the arc decreasing with the increase of the current, it follows that the light can not be proportional to the square of the current."

It is argued by many that an increase of energy in the arc produces a corresponding increase of temperature in the carbons, and that, according to a well-known law, the light must increase much faster than the temperature. But, in fact, after a certain point is reached, the temperature of the positive or light-giving carbon does not increase with increase of current, but the area of surface heated to maximum increases almost directly with the current. The "certain point" several times alluded to, is at that stage of the process when vaporization takes place over a well-defined spot on the positive carbon. Obviously, when rapid evaporation has commenced, the temperature of the carbon cannot be increased at that point, and an increase in the amount of heat evolved can only result in an increase in the rapidity of vaporization, or vaporization over an increased area.

A careful study of the voltaic arc, and of the carbon points after being used with currents of various strength, cannot fail to convince the most skeptical of the truth of these assertions.

Quite contradictory to the spirit of those portions of Mr. Schwendler's report, already quoted, he says in another place: "If more than one light is produced in the same circuit, by the same current, the external or available light becomes rapidly clearer with increase of the number of lights produced." For this reason already, if not for many others, the division of light must result in an engineering failure.

It seems scarcely possible that Mr. Schwendler could have overlooked the obvious fact that a current representing a given amount of energy, and adapted to produce the maximum light from one center, may, by having its dimensions suitably altered, *i. e.*, its electromotive force increased and its volume diminished, while its energy remains the same, be adapted to produce its maximum light from several small centers, instead of from one large one (provided, of course, the energy of each center is not reduced below the "certain point" before defined). Yet he seems to have overlooked or entirely ignored this fact.

The performance of the No. 7 Brush machine with its sixteen lamps, already detailed, proves unquestionably that the division of a large current energy among many lights in the same circuit, or, more properly, the multiplication of lights on a single circuit, has resulted in a great engineering success.

The votaries of the single-light system would advocate, in place of the No. 7 Brush machine, the use of sixteen small machines, with their costly system of conductors. Each of these would require as much attendance and involve as much expense for repairs as the single large machine. At least fifty per cent., and probably one hundred per cent., more driving power would be required to produce sixteen lights of the same size, and the first cost of the apparatus would be vastly greater. Further, if the lights were required at any considerable distance from the source of power the single-light system must prove entirely impracticable.

Since writing the above, a larger machine than the sixteen-light machine herein described has been completed and thoroughly tested. It gives forty lights in a single circuit, each light having the same length of arc and using the same volume of current as the sixteen-light machine. The electromotive force of this machine is about 2,200 volts, and the volume of the current 10 webers. The horse power required is 36, and the relative economy of this machine, as compared with the sixteen-light machine, is somewhat increased. A large number of these machines have already been ordered by manufacturing establishments and for lighting stations in cities and towns.

## M. WIEDEMANN'S ELECTRIC PAPER.

ORDINARY letter paper, if well heated and briskly rubbed with the hand or with a brush, acquires electric properties; it adheres to tables, walls, etc., and on contact with the hand it gives slight electric discharges, visible in the dark. But on taking Swedish filter paper, and submitting it to the treatment described below, its electric properties are greatly intensified, and sparks may be drawn from it several centimeters in length. The paper is steeped in a mixture of equal volumes of nitric and sulphuric acid, as in the manufacture of gun cotton. The paper thus pyrolyzed is washed with abundance of water and dried. If laid on a sheet of waxed paper and rubbed briskly it manifests energetic action, and may be used for the repetition of almost all experiments in static electricity. — *Comptes Rendus*.

A COSTLY LETTER ENVELOPE.—Among the curious articles in the Indian Court of the Melbourne Exhibition are two hollow elephant tusks fitted with a gold cover. They were sent to the Viceroy of India by the Rajah of Burmah, who used them as an envelope for an official communication. They are valued at \$1,000.

## THE TELEPHONIC SYSTEMS OF DR. CORNELIUS HERZ.

BY COUNT DU MONCEL.

Notwithstanding the progress accomplished in telephony since the origin of this invention, it had hitherto been impossible to obtain a clear and strong transmission of speech when the distances were somewhat large. This fact is proved by the discontent of many subscribers of telephonic exchanges, who often pretended that they were absolutely unable to hear anything with their telephones. It is true that this fault of hearing sometimes results from a constitution of the ear that is not well adapted for telephonic sounds, and especially from a bad education of the organ of hearing for that kind of correspondence. But we must also acknowledge that there exist many other causes which prevent the sounds that are produced by the telephones from being sonorous and clear, especially when these sounds have to be transmitted over a telegraphic line which is always influenced by accidental currents of all kinds, such as earth currents, induction currents, atmospheric currents, etc. In order to counteract these currents upon somewhat long lines, it is necessary that the undulatory currents that are transmitted have a certain amount of energy, and it was necessary, therefore, to employ telephones with which a battery was used. But on account of the fact that the variations of resistance depending upon the transmitting apparatus which furnishes the undulatory currents are relatively feeble in comparison to the resistance of the entire line, the inflections of the electric waves are not distinct enough to generate all those little sinuosities that correspond to articulate sound. These inflections become more or less effaced by the resistance of the line, and are partially suppressed by the accidental electrical currents which pass over them. In order to avoid this inconvenience it was necessary to solve two problems: (1) The amplitude of the electrical vibrations had to be greatly increased, without this increase of amplitude having to be required from the voice; and (2) electrical currents foreign to those transmitted had to be prevented from passing over the telephonic circuit. These two problems have been solved by Dr. Herz in his telephonic systems, of which we give to-day a complete description.

Several means may be used to obtain an increase in the strength of electrical waves: (1) The so-called derivation system. (2) Microphonic systems which offer a great number of contacts formed by bodies which are semi-conductors, but which are at the same time so arranged that the resistance is not too great. (3) When undulatory induction currents are used, the amplitude of the electric waves may be increased by augmenting the duration of these currents themselves. All of these means have been utilized and patented by Dr. Herz, and the good results that have been obtained are already known.

The second part of the problem has been solved by the same method which is employed in submarine cables, *viz.*, by an interruption of the circuit itself, either by placing condensers or apparatus that are able to diffuse the electric charges, such as lightning arresters (Carles) into the circuit. The problem was directly solved by introducing as receiver a speaking condenser in the circuit. When ordinary telephones were used the introduction of "carles" or condensers between the apparatus and the earth were sufficient. It is easily understood that the interruption of the circuit prevents accidental currents from being propagated, or if they are propagated—which may be the case when telephonic transmissions are obtained by means of open circuits—it prevents them from producing effects that are energetic enough to injure telephonic transmissions.

We will now speak of the arrangements that are employed in the system of Dr. Herz (Fig. 1).

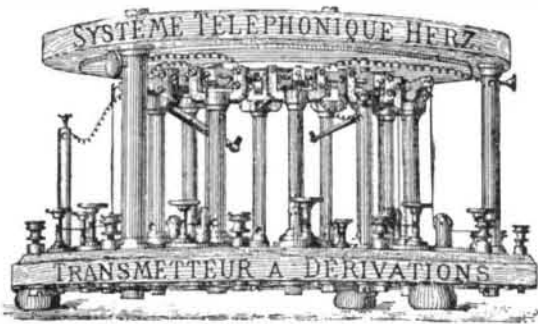


FIG. 1.

In the first system that was used in the experiments made last fall between Brest and Penzance, the transmitter was employed, the front view of which is represented in Fig. 1 and the ground plan in Fig. 2, while the electrical details are represented in Fig. 3.

In order to illustrate the principle of the apparatus, however, we must refer to Fig. 4, which gives a general view of the complete system, and is, as may be seen, intercalated at a derivation of the battery. On the other side the battery is the line with its different accessories. Each of its contact points is composed of a plate of carbon or of a plate of pyrite of iron, which are in contact either with pyrites of iron mounted upon balancing levers, the pressure of which is regulated by springs. These levers are placed upon metallic columns as shown in Fig. 1, and in order to better illustrate the arrangement, two of the contacts are shown in our Fig. 1 with lowered levers.

Six plates, consisting of semi-conductors, are arranged around the center of a vibrating disk, which forms the upper part of the apparatus (Figs. 2 and 3), and which serves as the diaphragm to be moved by the voice.

Each of the pyrite plates communicates with the contact-points of the elements of the battery, as seen in Figs. 3 and 4, in such a manner that the current generated in each element traverses each contact point.

The battery consists, therefore, of twelve elements, which are all united in tension.

In order that all contact points may form an uninterrupted chain from one end to the other, and in order that they may be also used separately, the points of the contact-lever are united by means of a conducting wire, consisting of two branches, which extend from one plate to the other, as seen in Figs. 3 and 4.

When we follow the course of the currents for some time, we see that the current of the first element at the left of the battery goes directly to the earth, passing the first contact at the left of plate No. 1.

The current of the second element goes also to the earth, passing the second contact of plate No. 1, and afterward the

first contact. The current of the third element passes the first contact at the left of plate No. 2, the first contact at the left of this plate, the branch-wire of the second contact of the first plate, the two contact points of this plate, and finally goes to the earth; the same is the case with all the remaining elements of the battery, which, being united in tension, are all in correspondence with the opposite side, *i. e.*, with the right hand side of the line.

As the first element at the left of the battery is, besides, in connection with the earth, so the currents of all the single elements of the battery have two ways upon which they may pass, *viz.*, the circuit consisting of the contact-points of the transmitter, and the circuit formed by the line. This arrangement has been made in order to diminish to a great extent the resistance of the twelve contact points of the transmitter, which is very considerable, in order to intercalate them at a derivation to the earth, and finally, in order to amplify the variations of resistance in the transmitter. Thus the amplification of the variations is obtained in a double manner: first, by the effects resulting from the derivation; secondly, by

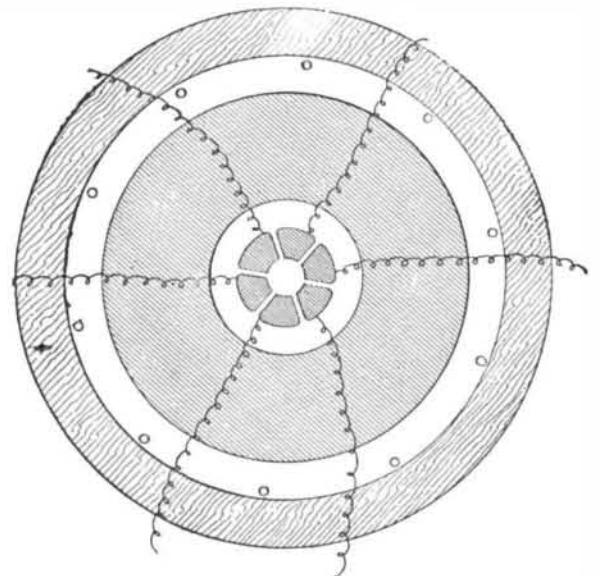


FIG. 2.

those resulting from the increase of the number of contact points, and by the fact that derivations are established at each element of the battery, the total resistance of the transmitter is greatly diminished.

A little calculation will be very useful, in order to get a correct idea of the importance which results from the use of the derivation system under such conditions. Let us call *b* the circuit of the line; *d*, the derivation circuit, consisting of the contact points of the transmitter; *E*, the electromotor force of the battery; and *r*, its resistance. According to Ohm's formulas, when the transmitter, having the resistance of *a*, is directly introduced into the circuit, the value of the intensity, *I*, may be found by the following formula:

$$I = \frac{E}{r + a + b}$$

and in a case where the transmitter forms the derivation, the value will be shown in the formula:

$$I = \frac{E}{r + \frac{rb}{a} + b}$$

This formula only differs from the former by the intermediary quantity between *r* and *b*, which is *a* in the first, and  $\frac{rb}{a}$  in the second case. It can easily be seen from these two

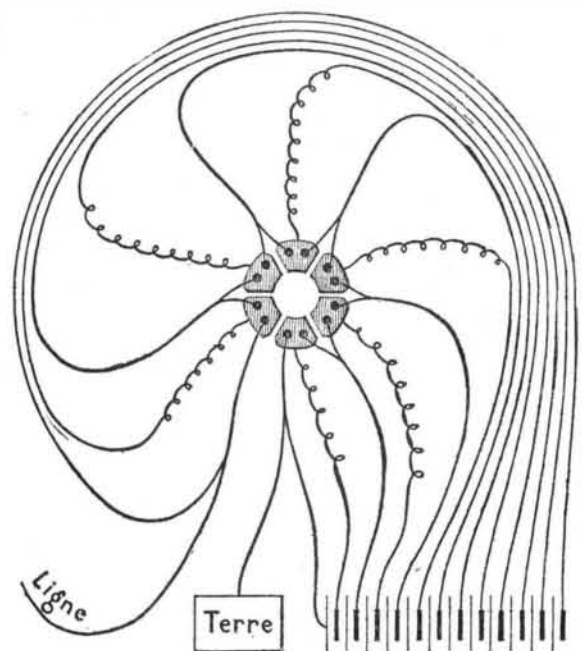


FIG. 3.

mathematical expressions that the variations of *a* must change the value of *I* in one case much more than in the other. Let us, for example, suppose that *r*=5 ohms, *a*=10 ohms, and *b*=100 ohms. The total resistance forming the divisor of *E* will be, in case of the use of a simple circuit, 5+10+100=115 ohms, and, in case a derivation system is employed, we will have:

$$5 + \frac{100 \times 5}{10} + 100 = 155$$

Now, let us suppose that in consequence of a change of pressure at the contact-points, *a* is reduced to two ohms, the resistance in the first case will then be equal to 113