Notes on a Unipolar Dynamo

by
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The Electrical Engineer
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It is characteristic of fundamental discoveries, of great achievements of intellect, that they retain an undiminished power upon the imagination of the thinker. The memorable experiment of Faraday with a disc rotating between the two poles of a magnet, which has borne such magnificent fruit, has long passed into every-day experience; yet there are certain features about this embryo of the present dynamos and motors which even to-day appear to us striking, and are worthy of the most careful study.

Consider, for instance, the case of a disc of iron or other metal revolving between the two opposite poles of a magnet, and the polar surfaces completely covering both sides of the disc, and assume the current to be taken off or conveyed to the same by contacts uniformly from all points of the periphery of the disc. Take first the case of a motor. In all ordinary motors the operation is dependent upon some shifting or change of the resultant of the magnetic attraction exerted upon the armature, this process being effected either by some mechanical contrivance on the motor or by the action of currents of the proper character. We may explain the operation of such a motor just as we can that of a water-wheel. But in the above example of the disc surrounded completely by the polar surfaces, there is no shifting of the magnetic action, no change whatever, as far as we know, and yet rotation ensues. Here, then, ordinary considerations do not apply; we cannot even give a superficial explanation, as in ordinary motors, and the operation will be clear to us only when we shall have recognized the very nature of the forces concerned and fathomed the mystery of the invisible connecting mechanism.

Considered as a dynamo machine, the disc is an equally interesting object of study. In addition to its peculiarity of giving currents of one direction without the employment of commutating devices, such a machine differs from ordinary dynamos in that there is no reaction between armature and field. The armature current tends to set up a magnetization at right angles to that of the field current, but since the current is taken off uniformly from all points of the periphery, and since, to be exact, the external circuit may also be arranged perfectly symmetrical to the field magnet, no reaction can occur. This, however, is true only as long as the magnets are weakly energized, for when the magnets are more or less saturated, both magnetizations at right angles seemingly interfere with each other.

For the above reason alone it would appear that the output of such a machine should, for the same weight, be much greater than that of any other machine in which the armature current tends to demagnetize the field. The extraordinary output of the Forbes unipolar dynamo and the experience of the writer confirm this view.

Again, the facility with which such a machine may be made to excite itself is striking, but this may be due — besides to the absence of armature reaction — to the perfect smoothness of the current and nonexistence of self-induction.

If the poles do not cover the disc completely on both sides, then, of course, unless the disc be properly subdivided, the machine will be very inefficient. Again, in this case there are points worthy of notice. If the disc be rotated and the field current interrupted, the current through the armature will continue to flow and the field magnets will lose their strength comparatively slowly. The reason for this will at once appear when we consider the direction of the currents set up in the disc.

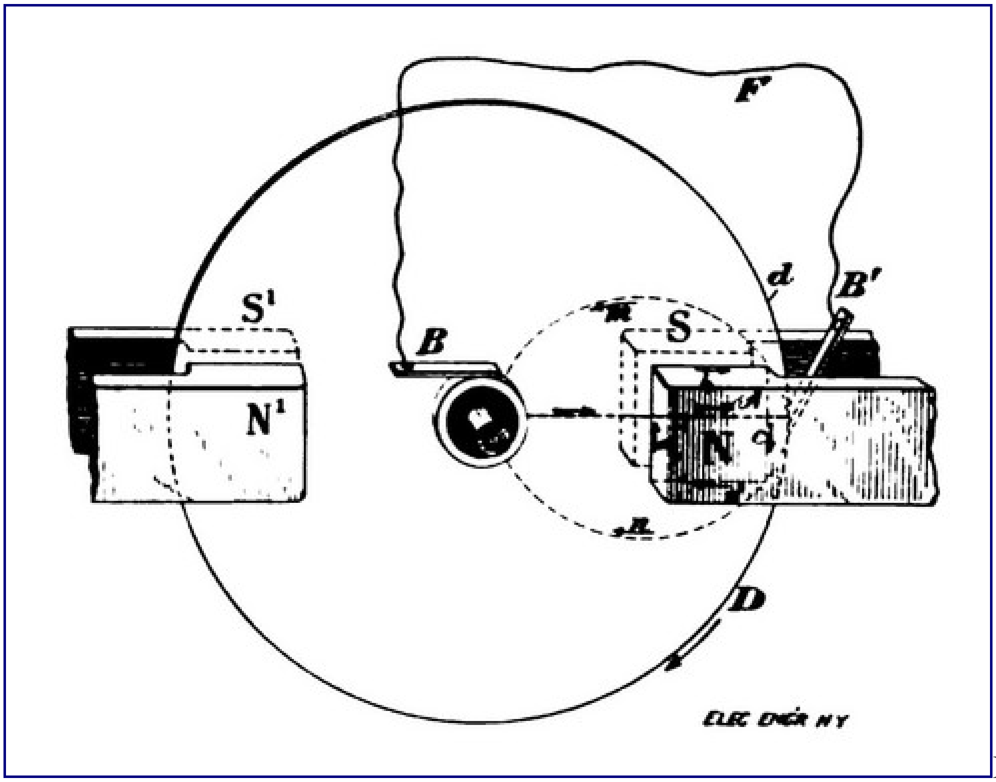
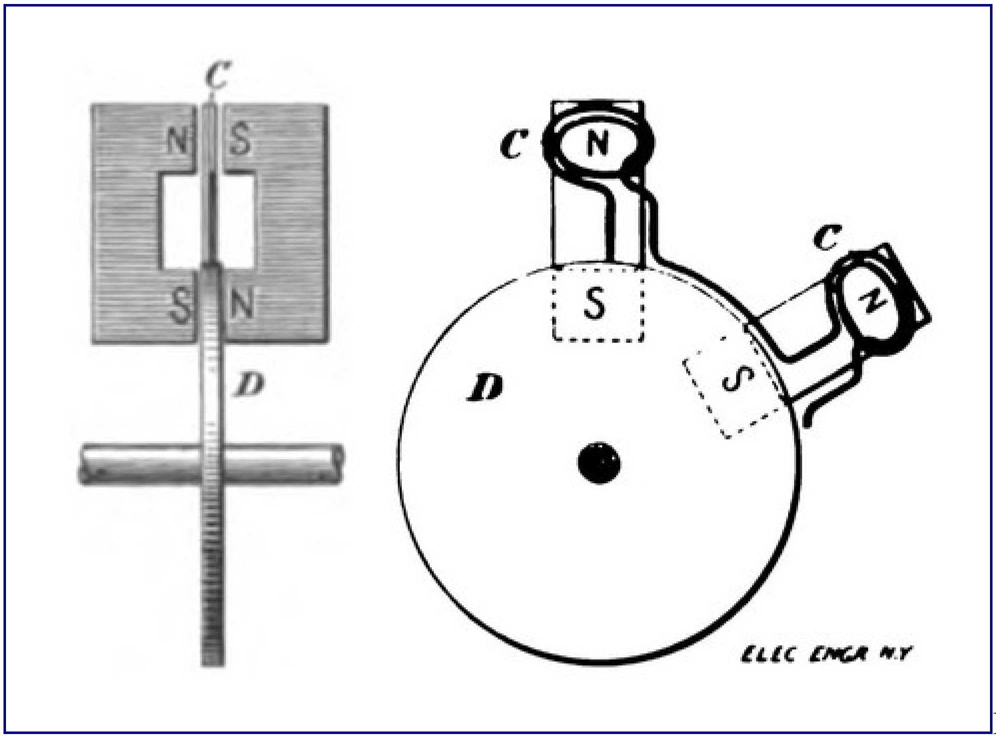


Fig. 1.

Referring to the diagram Fig. 1, *d* represents the disc with the sliding contacts *B B'* on the shaft and periphery. *N* and *S* represent the two poles of a magnet. If the pole N be above, as indicated in the diagram, the disc being supposed to be in the plane of the paper, and rotating in the direction of the arrow *D*, the current set up in the disc will flow from the centre to the periphery, as indicated by the arrow *A*. Since the magnetic action is more or less confined to the space between the poles *N S*, the other portions of the disc may be considered inactive. The current set up will therefore not wholly pass through the external circuit *F*, but will close through the disc itself, and generally, if the disposition be in any way similar to the one illustrated, by far the greater portion of the current generated will not appear externally, as the circuit *F* is practically short-circuited by the inactive portions of the disc. The direction of the resulting currents in the latter may be assumed to be as indicated by the dotted lines and arrows *m* and *n*; and the direction of the energizing field current being indicated by the arrows *a b c d*, an inspection of the figure shows that one of the two branches of the eddy current, that is, *A B' m B*, will tend to demagnetize the field, while the other branch, that is, *A B' n B*, will have the opposite effect. Therefore the branch *A B m B*, that is, the one which is *approaching* the field, will repel the lines of the same, while branch *A B' n B*, that is, the one *leaving* the field, will gather the lines of force upon itself.

In consequence of this there will be a constant tendency to reduce the current flow in the path *A B' m B*, while on the other hand no such opposition will exist in path *A B' n B*, and the effect of the latter branch or path will be more or less preponderating over that of the former. The joint effect of both the assumed branch currents might be represented by that of one single current of the same direction as that energizing the field. In other words, the eddy currents circulating in the disc will energize the field magnet. This is a result quite contrary to what we might be led to suppose at first, for we would naturally expect that the resulting effect of the armature currents would be such as to oppose the field current, as generally occurs when a primary and secondary conductor are placed in inductive relations to each other. But it must be remembered that this result from the peculiar disposition in this case, namely, two paths being afforded to the current, and the latter selecting that path which offers the least opposition to its flow. From this we see that the eddy currents flowing in the disc partly energize the field, and for this reason when the field current is interrupted the currents in the disc will continue to flow, and the field magnet will lose its strength with comparative slowness and may even retain a certain strength as long as the rotation of the disc is continued.

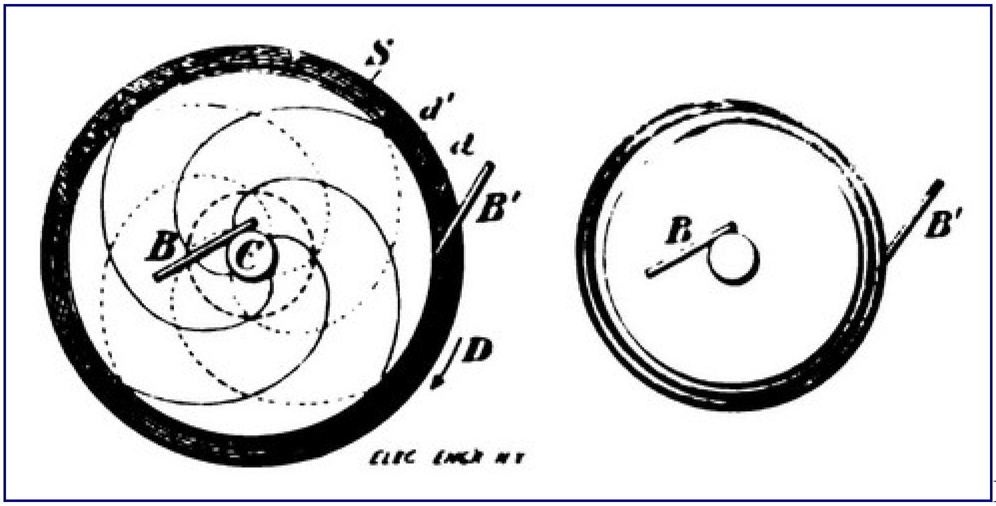
The result will, of course, largely depend on the resistance and geometrical dimensions of the path of the resulting eddy current and on the speed of rotation; these elements, namely, determine the retardation of this current and its position relative to the field. For a certain speed there would be a maximum energizing action; then at higher speeds, it would gradually fall off to zero and finally reverse, that is, the resultant eddy current effect would be to weaken the field. The reaction would be best demonstrated experimentally by arranging the fields *N S*, *N' S*, freely movable on an axis concentric with the shaft of the disc. If the latter were rotated as before in the direction of the arrow *D* the field would be dragged in the same direction with a torque, which, up to a certain point, would go on increasing with the speed of rotation, then fall off, and, passing through zero, finally become negative; that is, the field would begin to rotate in opposite direction to the disc. In experiments with alternate current motors in which the field was shifted by currents of differing phase, this interesting result was observed. For very low speeds of rotation of the field the motor would show a torque of 900 lbs. or more, measured on a pulley 12 inches in diameter. When the speed of rotation of the poles was increased the torque would diminish, would finally go down to zero, become negative, and then the armature would begin to rotate in opposite direction to the field.



Figs. 2 & 3.

To return to the principal subject; assume the conditions to be such that the eddy currents generated by the rotation of the disc strengthen the field, and suppose the latter gradually removed while the disc is kept rotating at an increased rate. The current, once started, may then be sufficient to maintain itself and even increase in strength, and then we have the case of Sir William Thomson's "current accumulator." But from the above considerations it would seem that for the success of the experiment the employment of a disc *not subdivided* would be essential, for if there should be a radial subdivision, the eddy currents could not form and the self-exciting action would cease. If such a radially subdivided disc were used it would be necessary to connect the spokes by a conducting rim or in any proper manner so as to form a symmetrical system of closed circuits.

The action of the eddy currents may be utilized to excite a machine of any construction. For instance, in Figs. 2 and 3 an arrangement is shown by which a machine with a disc armature might be excited. Here a number of magnets, *N S*, *N S*, are placed radially on each side of a metal disc *D* carrying on its rim a set of insulated coils, *C*, *C*. The magnets form two separate fields, an internal and an external one, the solid disc rotating in the field nearest the axis, and the coils in the field further from it. Assume the magnets slightly energized at the start; they could be strengthened by the action of the eddy currents in the solid disc so as to afford a stronger field for the peripheral coils. Although there is no doubt that under proper conditions a machine might be excited in this or a similar manner, there being sufficient experimental evidence to warrant such an assertion, such a mode of excitation would be wasteful.



Figs. 4 & 5.

But a unipolar dynamo or motor, such as shown in Fig. 1, may be excited in an efficient manner by simply properly subdividing the disc or cylinder in which the currents are set up, and it is practicable to do away with the field coils which are usually employed. Such a plan is illustrated in Fig. 4. The disc or cylinder *D* is supposed to be arranged to rotate between the two poles *N* and *S* of a magnet, which completely cover it on both sides, the contours of the disc and poles being represented by the circles *d* and *d'* respectively, the upper pole being omitted for the sake of clearness. The cores of the magnet are supposed to be hollow, the shaft *C* of the disc passing through them. If the unmarked pole be below, and the disc be rotated screw fashion, the current will be, as before, from the centre to the periphery and may be taken off by suitable sliding contacts, *B B'*, on the shaft and periphery respectively. In this arrangement the current flowing through the disc and external circuit will have no appreciable effect on the field magnet.

But let us now suppose the disc to be subdivided spirally, as indicated by the full or dotted lines, Fig. 4. The difference of potential between a point on the shaft and a point on the periphery will remain unchanged, in sign as well as in amount. The only difference will be that the resistance of the disc will be augmented and that there will be a greater fall of potential from a point on the shaft to a point on the periphery when the same current is traversing the external circuit. But since the current is forced to follow the lines of subdivision, we see that it will tend either to energize or de-energize the field, and this will depend, other things being equal, upon the direction of the lines of subdivision. If the subdivision be as indicated by the full lines in Fig. 4, it is evident that if the current is of the same direction as before, that is, from centre to periphery, its effect will be to strengthen the field magnet; whereas, if the subdivision be as indicated by the dotted lines, the current generated will tend to weaken the magnets. In the former case the machine will be capable of exciting itself when the disc is rotated in the direction of arrow *D*; in the latter case the direction of rotation must be reversed. Two such discs may be combined, however, as indicated, the two discs rotating in opposite fields, and in the same or opposite direction.

Similar dispositions may, of course, be made in a type of machine in which, instead of a disc, a cylinder is rotated. In such unipolar machines, in the manner indicated, the usual field coils and poles may be omitted and the machine may be made to consist only of a cylinder or of two discs enveloped by a metal casting.

Instead of subdividing the disc or cylinder spirally, as indicated in Fig. 4, it is more convenient to interpose one or more turns between the disc and the contact ring on the periphery, as illustrated in Fig. 5.

A Forbes dynamo may, for instance, be excited in such a manner. In the experience of the writer it has been found that instead of taking the current from two such discs by sliding contacts, as usual, a flexible conducting belt may be employed to advantage. The discs are in such case provided with large flanges, affording a very great contact surface. The belt should be made to bear on the flanges with spring pressure to take up the expansion. Several machines with belt contact were constructed by the writer two years ago and worked satisfactorily, but for want of time the work in that direction has been temporarily suspended. A number of features pointed out above have also been used by the writer in connection with some types of alternating current motors.

UNITED STATES PATENT OFFICE.

NIKOLA TESLA, OF NEW YORK, N. Y., ASSIGNOR OF TWO-THIRDS TO CHARLES F. PECK, OF ENGLEWOOD, NEW JERSEY, AND ALFRED S. BROWN, OF NEW YORK, N. Y.

TESLA PATENT 406,968 DYNAMO-ELECTRIC MACHINE.

SPECIFICATION forming part of Letters Patent No. 406,968, dated July 16, 1889.

Application filed March 23, 1889. Serial No. 304,498. (No model.)

To all whom it may concern:

Be it known that I, NIKOLA TESLA from Smiljan, Lika, border country of Austria-Hungary, a subject of the Emperor of Austria, and a resident of New York, in the county and State of New York, have invented certain new and useful Improvements in Dynamo or Magneto Electric Machines, of which the following is a specification, reference being had to the accompanying drawings.

This invention relates to that class of electrical generators known as "unipolar," in which a disk or cylindrical conductor is mounted between magnetic poles adapted to produce an approximately-uniform field. In the first-named or disk armature machines the currents induced in the rotating conductor flow from the center to periphery, or conversely, according to the direction of rotation or the lines of force as determined by the signs of the magnetic poles, and these currents are taken off usually by connections or brushes applied to the disk at points on its periphery and near its center. In the case of the cylindrical armature-machine the currents developed in the cylinder are taken off by brushes applied to the sides of the cylinder at its ends.

In order to develop economically an electro-motive force available for practicable purposes, it is necessary either to rotate the conductor at a very high rate of speed or to use a disk of large diameter or cylinder of great length; but in either case it becomes difficult to secure and maintain a good electrical connection between the collecting-brushes and the conductor, owing to the high peripheral speed.

It has been proposed to couple two or more disks together in series with the object of obtaining a higher electro-motive force; but with the connections heretofore used and using other conditions of speed and dimension of disk necessary to securing good practicable results this difficulty is still felt to be a serious obstacle to the use of this kind of generator. These objections I have sought to avoid; and for this purpose I construct a machine with two fields, each having a rotary conductor mounted between its poles, but the same principle is involved in the case of both forms of machine above described, and as I prefer to use the disk form I shall confine the description herein to that machine. The disks are formed with flanges, after the manner of pulleys, and are connected together by flexible conducting bands or belts.

I prefer to construct the machine in such manner that the direction of magnetism or order of the poles in one field of force is opposite to that in the other, so that rotation of the disks in the same direction develops a current in one from center to circumference and in the other from circumference to center. Contacts applied therefore to the shafts upon which the disks are mounted form the terminals of a circuit the electro-motive force in which is the sum of the electro-motive forces of the two disks.

I would call attention to the obvious fact that if the direction of magnetism in both fields be the same the same result as above will be obtained by driving the disks in opposite directions and crossing the connecting-belts. In this way the difficulty of securing and maintaining good contact with the peripheries of the disks is avoided and a cheap and durable machine made which is useful for many purposes—such as for an exciter for alternating-current generators, for a motor, and for any other purpose for which dynamo-machines are used.

The specific construction of the machine which I have just generally described I have illustrated in the accompanying drawings, in which—

Figure 1 is a side view, partly in section, of my improved machine. Fig. 2 is a vertical section of the same at right angles to the shafts.

In order to form a frame with two fields of force, I cast a support A with two pole-pieces B B' integral with it. To this I join by bolts E a casting D, with two similar and corresponding pole-pieces C C'. The pole-pieces B B' are wound or connected to produce a field of force of given polarity, and the pole-pieces C C' are wound or connected to produce a field of opposite polarity. The driving-shafts F G pass through the poles and are journaled in insulating-bearings in the casting A D, as shown.

H K are the disks or generating-conductors. They are composed of copper, brass, or iron and are keyed or secured to their respective shafts. They are provided with broad peripheral flanges J. It is of course obvious that the disks may be insulated from their shafts, if so desired. A flexible metallic belt L is passed over the flanges of the two disks, and, if desired, may be used to drive one of the disks. I prefer, however, to use this belt merely as a conductor, and for this purpose may use sheet steel, copper, or other suitable metal. Each shaft is provided with a driving-pulley M, by which power is imparted from a counter-shaft.

N N are the terminals. For sake of clearness they are shown as provided with springs P, that bear upon the ends of the shafts. This machine, if self-exciting, would have copper bands around its poles, or conductors of any kind—such as the wires shown in the drawings—may be used.

I do not limit my invention to the special construction herein shown. For example, it is not necessary that the parts be constructed in one machine or that the materials and proportions herein given be strictly followed. Furthermore, it is evident that the conducting belt or band may be composed of several smaller bands and that the principle of connection herein described may be applied to more than two machines.

What I claim is—

1. An electrical generator consisting of the combination, with two rotary conductors mounted in unipolar fields, of a flexible conductor or belt passing around the peripheries of said conductors, as herein set forth.

2. The combination, with two rotary conducting-disks having peripheral flanges and mounted in unipolar fields, of a flexible conducting belt or band passing around the flanges of both disks, as set forth.

3. The combination of independent sets of field-magnets adapted to maintain unipolar fields, conducting-disks mounted to rotate in said fields, independent driving mechanism for each disk, and a flexible conducting belt or band passing around the peripheries of the disks, as set forth.

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DYNAMO ELECTRIC MACHINE.

No. 406,968. Patented July 16, 1889.

Fig. 1

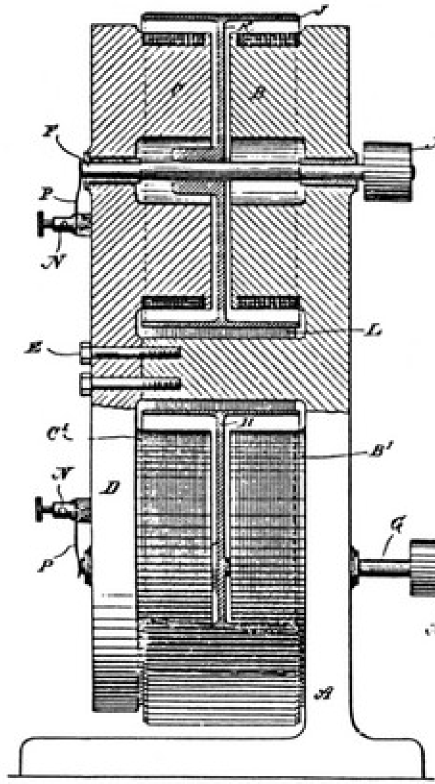
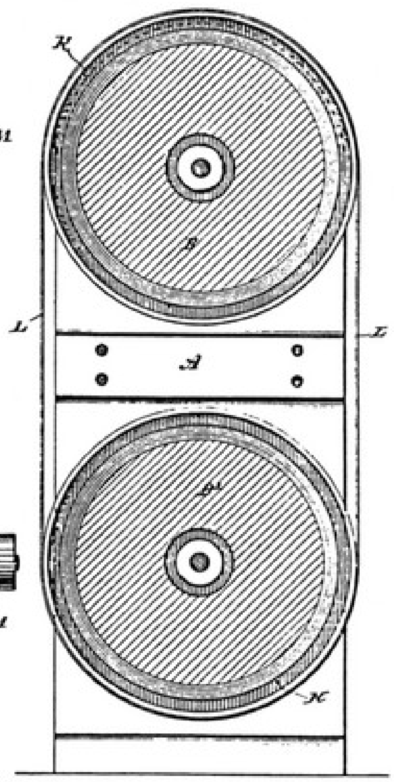


Fig. 2



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DYNAMO ELECTRIC MACHINE.

No. 338,169.

Patented Mar. 16, 1886.

Fig. 1.

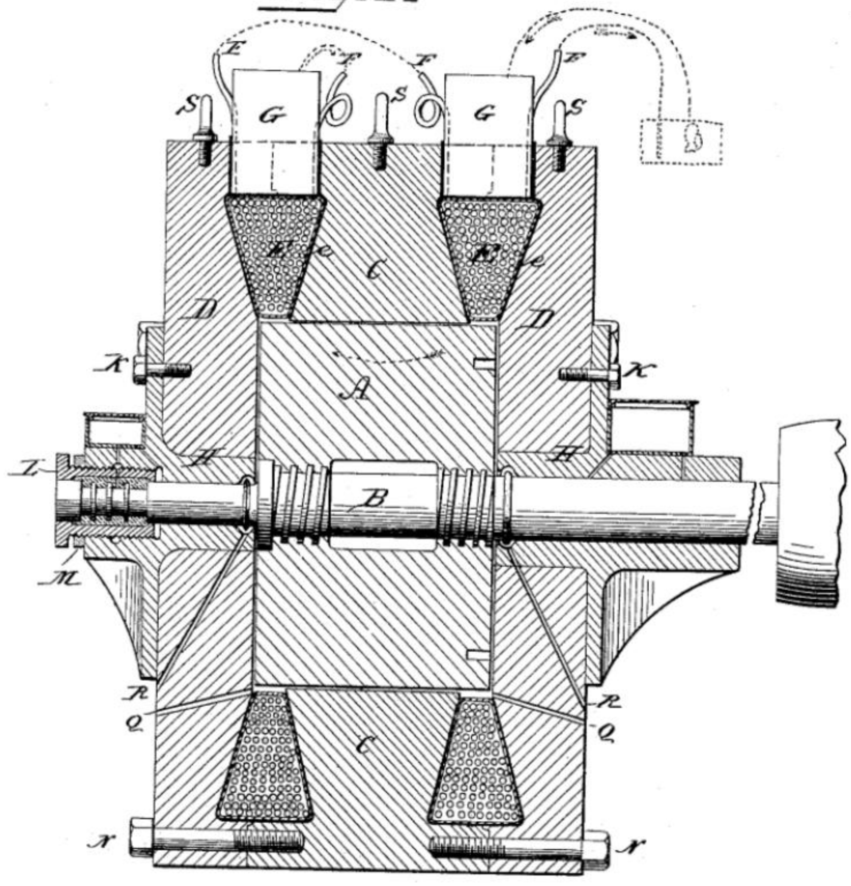

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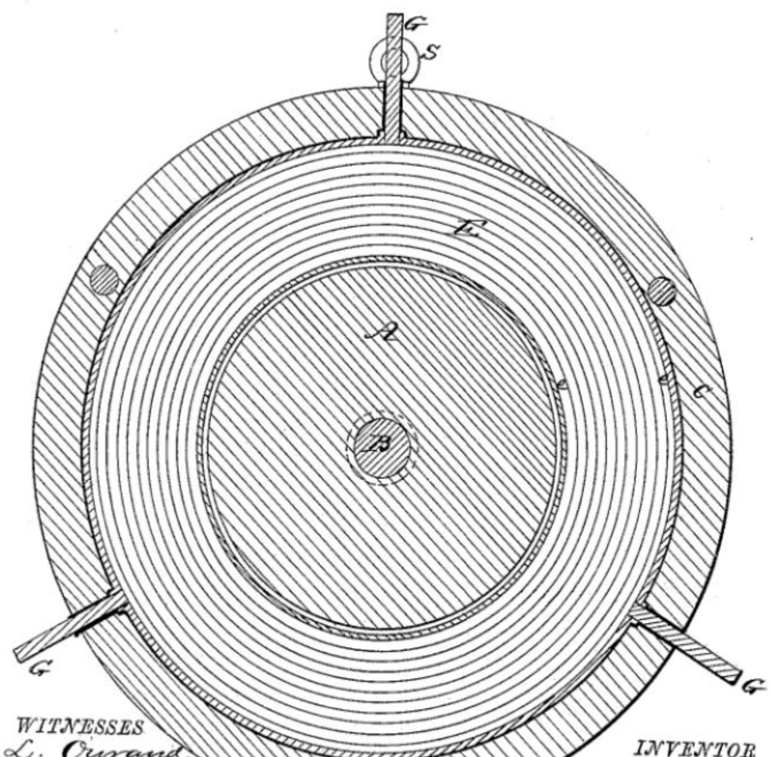
Fig. 5.

Fig. 2.



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DYNAMO ELECTRIC MACHINE.

No. 338,169.

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Fig. 3

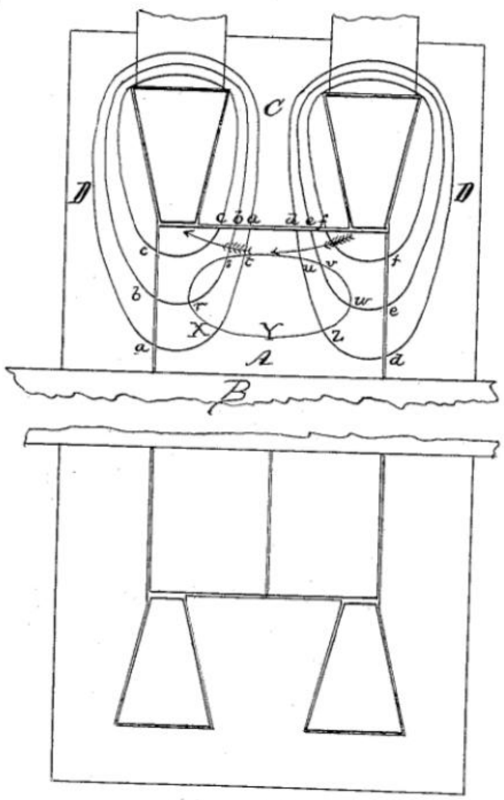

Fig. 3a

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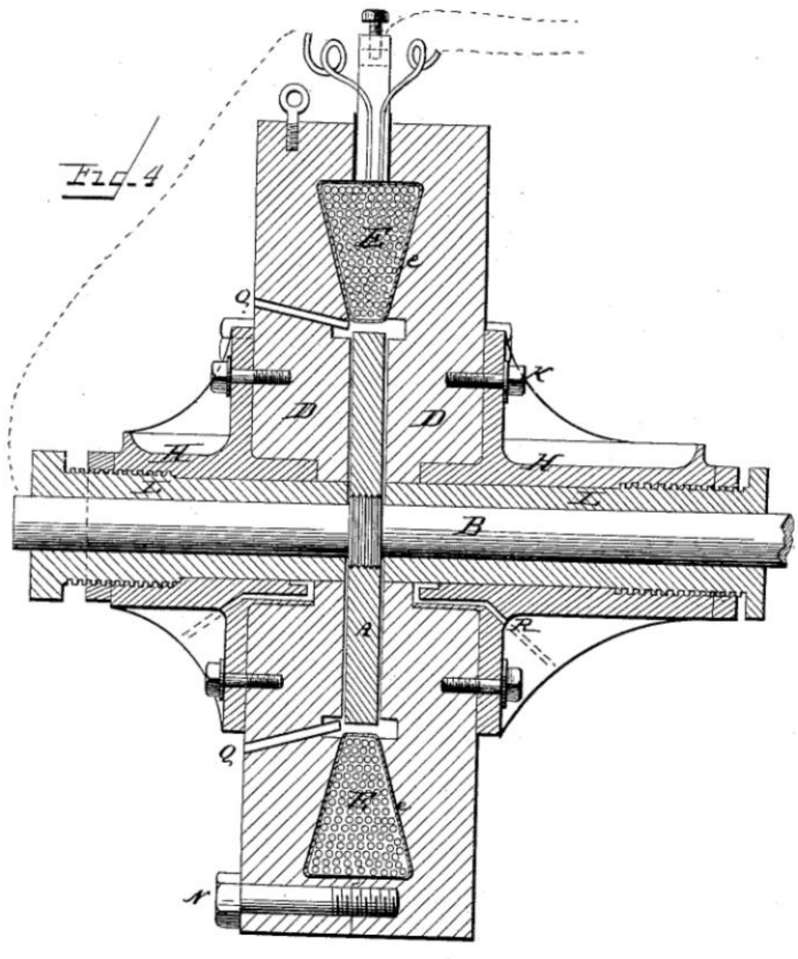
Fig. 4



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DYNAMO-ELECTRIC MACHINE.

SPECIFICATION forming part of Letters Patent No. 338,169, dated March 16, 1886.

Application filed October 11, 1884. Serial No. 145,209. (No model.) Patented in England June 22, 1883, No. 3,115, and in France December 19, 1883, No. 159,262.

To all whom it may concern:

Be it known that I, GEORGE FORBES, a subject of the Queen of Great Britain, residing at London, in the county of Middlesex, England, have invented certain new and useful Improvements in Machines for Generating Electricity, (patented in England June 22, 1883, No. 3,115, and in France December 19, 1883, No. 159,262;) and I do hereby declare the following to be a full, clear, and exact description of the invention, reference being had to the accompanying drawings, which form part of this specification.

My invention has relation to a machine for generating constant currents of electricity by the revolution of a mass of magnetized material without coils within the influence of a mass of iron provided with magnetizing-coils, and constituting the field of force under such conditions that the lines of force set up in the mass constituting the armature will converge toward one of the poles thereof, situated between two poles opposed thereto, while the electric currents set up by reason of a difference of potential between different points in the moving mass will be caused to intersect each line of force at one point, and may be collected from the surface of such mass.

My invention consists, essentially, in a machine for generating electric currents under the conditions above stated, and comprising a revolving mass of magnetic material constituting a naked armature, an encompassing mass of magnetic material, within which are embedded the magnetizing-coils and which constitutes the field, and means for collecting the currents of electricity from the surface of the armature.

While the details of construction of machines embodying my invention are susceptible of various modifications without departing from the spirit thereof, as will be presently indicated, I will now describe, specifically, a preferable form and arrangement which is at once simple and effective.

In this machine the armature is a single cylindrical body of iron mounted on a shaft, and the field-magnet is a box-like mass of iron completely encompassing the armature, and provided with openings in the sides for the passage of the armature-shaft. The magnetizing-coils which serve to magnetize both the field-magnet and the armature are set in metallic troughs embedded in and insulated from the field-magnet and surround the ends of the armature, a connection being established between the interiors of the troughs and the periphery of the armature for the passage of the current from one trough to the other through the armature, the conductors for completing the electric circuit being connected with the troughs. The energizing-current passes through the coils in opposite directions, respectively, whereby the armature is so magnetized that it has like poles at either end and an opposite pole at the middle of its periphery, and the polar points of the field-magnet are in opposition thereto.

In the accompanying drawings, Figure 1 is a vertical section of the machine along the axis of the shaft; Fig. 2, a cross-section through either end of the armature; Fig. 3, a diagram illustrating the direction of the lines of force and of the electric current. Fig. 3ᵃ is a modification showing two cylinder disk-armatures; Fig. 4, a vertical section of a modified form of machine, and Fig. 5 a detail.

A is a revolving cylinder of iron, which may be in one or several pieces.

B is a spindle, preferably of non-magnetic material, to which the armature A is attached in any suitable manner.

C C is an annular mass of soft iron, to which are attached, on either side, two masses of iron, D D, secured by bolts N N. The cylinder A fits very closely in the space inclosed by the masses C D.

E E are the exciting-coils, inclosed in the troughs or copper casings *e e*, which are insulated from the masses C and D D, in which they are placed. To prevent electrical contact between opposing faces of the field-magnet and armature, these faces of the field-magnet may be coated with an insulating-varnish.

F F are the terminals of the exciting-coils E E. These terminals pass through holes in the copper casings *e e* and in the iron masses.

G G are the positive and negative terminals of the machine. They are attached three to each of the copper casings, and pass through holes in the iron masses lined with insulating material.

H H are supports for the spindle of the armature, attached to the iron masses D D by the bolts K K.

L is a thrust-bearing screwing into the support H, by which the armature may be adjusted longitudinally on the shaft.

M is a jam-nut, by means of which the armature is fixed in its adjusted position.

Q Q are holes, insulated inside, for mercury to be poured into and out of the space between the armature A and the copper casings *e e*. The inner surfaces of the copper casings are not insulated, but may be electroplated with nickel to prevent amalgamation. The holes Q Q are furnished with plugs, by which they may be closed.

R R are channels to drain the surplus oil, the journals being lubricated by any suitable lubricant.

The coils of wire in E E are so connected that the magnetizing-current goes in opposite directions, respectively, in the two coils. The current may be derived from a separate source; or the coils of wire in E E may form part of the circuit through which the useful current passes, or they may be in a shunt of the useful-current circuit.

S S are rings by which the masses C and D D are lifted.

When using mercury contacts, I sometimes cut slots in the faces of the armature, or otherwise raise or depress a portion of the surface, to insure the rotation of and consequent centrifugal action of the mercury.

I do not wish to be understood as limiting myself to the employment of mercury for the purpose of maintaining electrical contact between the troughs and the armature, as, instead of a mercury contact, I may use copper bands or rings armed with inwardly-projecting brushes, which press against the periphery of the armature, such bands or rings being connected with or forming a part of the troughs. Any other expedient for maintaining contact without impeding the movement of the armature may be employed.

The parts D D are so proportioned that a line drawn from any part of E to the exterior and rotated about the axis will generate a surface of an area not less than the face of the cylinder A, and similar proportions are given to the mass C. This is important to observe, in order to prevent crowding together of the lines of force emanating from the face of the cylinder, which would be injurious to the efficiency of the machine.

All the lines of force in the machine represented pass almost continuously through iron, and this is an important feature of the machine.

The magnetizing-current is passed in opposite directions through the coils; hence the lines of force created by the coils converge from the two ends of the armature to the middle of its periphery, and an electro-motive force is set up at every point of the armature perpendicular to these lines of force and to the direction of motion. When the circuit is complete, this creates an electric current crossing all the lines of force, commencing at one of the terminals of the armature and passing through the armature to the other terminal. The same result would be obtained with any other shape of armature if its terminals lie upon any part of the inclosures E E, respectively.

Referring to the diagram Fig. 3, it will be observed that no local circuits can be set up in the mass of the armature. If there be two points, X Y, chosen at any positions in the mass, a line joining them cuts the lines of force, and it might be supposed that a local current could be set up; but such a current going from X to Y must have a return-circuit. This return-circuit cuts the lines of force and creates an electro-motive force, which will always be found to be exactly opposed in amount to that created in the other part of the circuit XY. Thus every closed circuit in the mass of the armature has equal opposing electro-motive forces, which prevent the creation of any current whatsoever. Thus in the diagram *a a b b* are the lines of force, and the electro-motive force created from X to Y is proportional to the number of lines of force cut by X Y. In this case it is one—namely, the line *a a*. Now take any return-circuit, (X *r s t u v w z* Y.) It cuts the lines *b b* twice in opposite directions, which destroy each other. So with the lines *d d e e*, and in cutting again the line *a a* at *t* the electro-motive force of X Y is destroyed. So, also, every complete circuit must cut each line of force an equal number of times in opposite directions.

My invention, as hereinbefore stated, admits of various modifications of structure and mechanical details without departure from its spirit. Thus, for instance, as shown in Fig. 3ª, instead of a single cylinder constituting the armature, two disks mounted upon a shaft, each surrounded by a coil and both inclosed in the same mass of iron, may be employed, in which case the exterior face of each disk will form like poles, and opposite poles will be formed on the interior faces, the poles of the field-magnet being opposed to these.

In Fig. 4 of the drawings I have illustrated a modified form of machine, wherein the armature is a single disk of iron surrounded by a single coil and encompassed by a mass of iron constituting the field-magnet. In this form the disk has opposite poles, respectively, on each side, and the poles of the field-magnet are opposed thereto. The electric current passes from the periphery of the disk to its center, and is taken off from the shaft by a suitable collector, D'.

It would not be a departure from the spirit of my invention to place permanent magnets in a part of the magnetic circuit, in which case no coils would be required.

Having fully described my invention, what I claim, and desire to secure by Letters Patent, is—

1. In a machine for generating electricity of the unipolar type, the combination, with a rotating magnetized mass and a box-like mass of magnetic material recessed for the reception of magnetizing-coils, of metallic troughs inclosing said coils and inserted in said recesses, said troughs being insulated from the walls of said recesses, but in circuit with the rotating mass, substantially as described.

2. A magnetic circuit of iron in which all the lines of force are closed curves, a part of the iron being adapted to rotate about a central axis, whereby an electric circuit is generated in the rotating mass, the terminals from which said current is collected being one within and the other without all the circuits of lines of force.

In testimony that I claim the foregoing I have hereunto set my hand this 8th day of October, 1884.

GEORGE FORBES.

Witnesses:
EWELL A. DICK,
JOS. B. CONNOLLY.