A.D. 1886, 9th February. N° 1877.

PROVISIONAL SPECIFICATION.

Improvements in Electric Lamps.

I Nikola Tesla, formerly of Smiljan Lika, border Country of Austro-Hungary, but now of Main Street, Rahway, State of New Jersey, United States of America Electrician do hereby declare the nature of this invention to be as follows:—

In these improvements I make use of two helices, one in a shunt and the other in the main circuit that includes the carbons.

An armature lever swings between the upper ends of the cores of these helices and at the other ends of the cores are pole pieces between which is an armature that is connected to a tubular clamp around the upper carbon holder, and this tubular clamp is suspended from the aforesaid armature lever. The cores and pole pieces of said helices, the swinging armature lever and the armature of the clamp, form a compound magnet.

The electric current passes from the + binding post through the shunt helix of high resistance to the — binding post, also from the + binding post the current passes through the carbon holders and carbons to the main line helix, and a branch from this helix goes to the — binding post and the end of said helix is connected to one of the pole pieces of the shunt magnet and is insulated. When the energy of the shunt core is increased by the increased resistance of the arc, the clamp is moved to allow the carbons to feed, and when the current through the shunt is abnormally strong, the armature of the clamp coming into contact with the pole of the shunt magnet, closes a branch circuit, that allows the electric current to pass through the clamp and the branch and a part of the main helix to the negative binding post, so that the continuity of the circuit is preserved and the shunt magnet is not injured, and as soon as the carbons come into contact and a path for the current is re-established through them, the carbons are separated to form the arc.

The ends of the swinging armature lever are curved, so also are the adjacent pole pieces of the respective cores and the poles at the other ends of the cores converge to the faces that act upon the armature at the bottom of the tubular clamp, and there is a spring that tends to swing the armature clamp away from the aforesaid insulated pole pieces.

Dated this 9th day of February 1886.

BREWER & SON,
For the Applicant.

COMPLETE SPECIFICATION.

Improvements in Electric Lamps.

I, NIKOLA TESLA, formerly of Smiljan Lika, border Country of Austro-Hungary, but now of Main Street, Rahway State of New Jersey, United States of America, Electrician, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

My invention relates more particularly to those arc-lamps in which the separation and feed of the carbon electrodes, or their equivalents, is accomplished by means of electro-magnets or solenoids in connection with suitable clutch mechanism and it is designed to remedy certain faults common to the greater part of the lamps heretofore made.

The objects of my invention are to prevent the frequent vibrations of the movable electrode and flickering of the light arising therefrom, to prevent the electrodes falling into contact, to dispense with the dash-pot, clock work or gearing and similar devices heretofore used and to render the lamp extremely sensitive and to feed the carbon almost imperceptibly and thereby obtain a very steady and uniform light.

In my present invention I further provide means for automatically withdrawing a lamp from the circuit or cutting out the same, when from a failure of the feed the arc reaches an abnormal length, and also means for automatically reinserting such lamp in the circuit when the rod drops and the carbons come into contact.

My invention will be understood with reference to the accompanying drawings in which

Fig. 1. is an elevation of the lamp with the case in section.

Fig. 2. is a sectional plan at the line x^1 x^1.

Fig. 3. is an elevation of the lamp partly in section, at right angles to fig. 1.

Fig. 4. is a sectional plan at the line *y. y.* fig. 1.

Fig. 5. is a section of the clamp in about full size.

Fig. 6. is a detached section illustrating the connection of the spring to the lever that carries the pivots of the clamp, and

Fig. 7. is a diagram showing the circuit connections of the lamp.

M. represents the main and N. the shunt magnet, both securely fastened to the base A. which with its side columns *s. s.* is preferably cast in one piece of brass or other diamagnetic material. To the magnets are soldered or otherwise fastened the brass washers or disks *a. a. a. a.* Similar washers *b. b.* of fiber or other insulating material serve to insulate the wires from the brass washers.

The magnets M and N. are made very flat so that their width exceeds three times their thickness or even more. In this way a comparatively small number of convolutions is sufficient to produce the required magnetism; besides a greater surface is offered for cooling off the wires.

The upper pole pieces *m. n.* of the magnets are curved as indicated in the drawing fig. 1; the lower pole pieces m^1 n^1 are brought near together tapering towards the armature *g.* as shown in figs. 2. and 4.

The object of this taper is to concentrate the greatest amount of the developed magnetism upon the armature and also to allow the pull to be exerted always upon the middle of the armature *g.*

This armature *g.* is a piece of iron in the shape of a hollow cylinder having on each side a segment cut away, the width of which is equal to the width of the pole-pieces m^1 n^1.

The armature is soldered or otherwise fastened to the clamp *r.* which is formed of a brass tube provided with gripping-jaws *e. e.* fig. 5.

These jaws are arcs of a circle of the diameter of the rod R. and are made of some hard metal, preferably of hardened German Silver. I also make the guides *f. f.* through which the carbon holding rod R slides, of the same material.

This has the advantage to reduce greatly the wear and corrosion of the parts coming in frictional contact with the rod which frequently causes trouble.

The jaws *e. e.* are fastened to the inside of the tube *r.* so that one is a little lower than the other.

The object of this is to provide a greater opening for the passage of the rod when the same is released by the clamp.

The clamp *r.* is supported on bearings *w. w* figs. 1. 3. and 5. which are just in the middle between the jaws *e. e*: I find this disposition to be the best. The bearings *w. w.* are carried by a lever *t.* one end of which rests upon an adjustable support *q.* of the side columns *s.* the other end being connected by means of the link e^1 to the armature lever L. The armature lever L. is a flat piece of iron in Z shape having its ends curved so as to correspond to the form of the upper pole pieces of the magnets M and N. It is hung upon the pivots *v.-v.* fig. 2. which are in the jaw *x.* of the top-plate B. This plate B. with the jaw is preferably cast in one piece and screwed to the side columns *s. s.* that extend up from the base A.

To partly balance the overweight of the moving parts, a spring s^1 figs. 2. and 6. is fastened to the top plate B. and hooked to the lever *t.*

The hook *o.* is towards one side of the lever or bent a little sideways, as seen in fig. 6. By this means a slight tendency is given to swing the armature towards the pole-piece m^1 of the main magnet to aid in clamping the rod.

The binding posts K. K^1 are preferably screwed to the base A. A manual switch for short circuiting the lamp when the carbons are renewed is also to be fastened to the base. This switch is of ordinary character and is not shown in the drawing. The rod R. is electrically connected to the lamp frame by means of a flexible conductor or otherwise.

The lamp case receives a removable ornamental cover s^2 around the same to enclose the parts.

The electrical connections are as indicated diagramatically in fig. 7.

The wire in the main magnet consists of two parts x^1 and p^1. These two parts may be in two separated coils or in one single helix as shown in the drawing. The part x^1 being normally in circuit is with the fine wire upon the shunt magnet wound and traversed by the current in the same direction so as to tend to produce similar pole pieces N. N. or *s. s.* on the corresponding pole pieces of the magnets M and N.

The part p^1 is only in circuit when the lamp is cut out and then the current being in the opposite direction produces in the main magnet, magnetism of the opposite polarity.

The operation is as follows :—

At the start the carbons are to be in contact and the current passes from the positive binding post K. to the lamp-frame, carbon-holder upper and lower carbon, insulated return wire in one of the side rods and from there through the part x^1 of the wire on the main magnet to the negative binding post. Upon the passage of the current, the main magnet is energized and attracts the clamping armature *g.* with sufficient force to clamp firmly the rod by means of the gripping jaws *e. e.* At the same time the armature lever L. is pulled down and the carbons separated.

In pulling down the armature lever L. the main magnet is assisted by the shunt magnet N. the latter being magnetized by magnetic induction from the magnet M.

It will be seen that the armatures L. & *g.* are practically the keepers for the magnets M. and N. and owing to this fact both magnets with either one of the armatures L and *g.* may be considered as one horseshoe magnet which might be termed a compound magnet. The whole of the soft iron parts *m.* m^1 *g.* *n.* n^1 and L form a compound magnet.

The carbons being separated, the fine wire receives a portion of the current, now the magnetic induction from the magnet M. is such as to produce opposite poles on the corresponding ends of the magnet N. but the current traversing the helices tends to produce similar poles on the corresponding ends of both magnets and therefore as soon as the fine wire is traversed by sufficient current, the magnetism of the whole compound magnet is diminished. With regard to the armature *g* and the operation of the lamp, the pole m^1 may be termed as the clamping and the pole n^1 as the releasing pole.

As the carbons burn away, the fine wire receives more current and the magnetism diminishes in proportion. This causes the armature lever L. to swing and the armature *g.* to descend gradually under the weight of the moving parts until the end *p.* fig. 1. strikes a stop on the top-plate B. The adjustment is such that when this takes place the rod R. is yet gripped securely by the jaws *e. e.*

The further downward movement of the armature lever being prevented, the arc becomes longer as the carbons are consumed and the compound magnet is weakened more and more until the clamping armature *g.* releases the hold of the gripping jaws *e. e.* upon the rod R. and the rod is allowed to drop a little shortening thus the arc. The fine wire now receiving less current, the magnetism increases and the rod is clamped again and slightly raised if necessary. This clamping and releasing of the rod continues until the carbons are consumed. In practice, the feed is so sensitive that for the greatest part of the time the movement of the rod cannot be detected without some actual measurement. During the normal operation of the lamp, the armature lever L. remains stationary or nearly so in the position shown in fig. 1. Should it arise that owing to an imperfection in the rod, the same and the carbon drop too far so as to make the arc too short, or even bring the carbons in contact, then a very small amount of current passes through the fine wire and the compound magnet becomes sufficiently strong to act as on the start in pulling the armature lever L. down and separating the carbons to a greater distance. It occurs often in practice that the rod sticks in the guides. In this case the arc reaches a great length until it finally breaks; then the light goes out and frequently the fine wire is injured.

To prevent such an accident I provide my lamp with an automatic cut-out.

This cut-out operates as follows:—When upon a failure of the feed the arc reaches a certain predetermined length, such an amount of current is diverted through the fine-wire that the polarity of the compound magnet is reversed.

The clamping armature *g.* is now moved against the shunt magnet N. until it strikes the releasing pole n^1. As soon as the contact is established, the current passes from the positive binding post over the clamp *r.* armature *g.* insulated shunt magnet and the helix p^1 upon the main magnet M. to the negative binding post. In this case the current passes in the opposite direction and changes the polarity of the magnet M. at the same time maintaining, by magnetic induction, in the core of the shunt magnet, the required magnetism without reversal of polarity and the armature *g.* remains against the shunt magnet pole n^1. The lamp is thus cut out as long as the carbons are separated, but the clamp has released its hold upon the rod hence the rod can drop by gravity so as to bring the carbons into contact.

The cut-out may be used in this form without any further improvement, but I prefer to arrange it so that if the rod drops and the carbons come into contact, the arc is started again. For this purpose I proportion the resistance of the part p^1 and the number of the convolutions of the wire upon the main magnet, so that when the carbons come into contact, a sufficient amount of current is diverted through the carbons and the part x^1 to destroy or neutralize the magnetism of the compound magnet. Then the armature *g.* having a slight tendency to approach to the clamping pole m^1 comes out of contact with the releasing pole n^1. As soon as this happens, the current through the part p^1 is interrupted and the whole current passes through the part x^1.

The magnet M. is now strongly magnetized, the armature *g.* is attracted and the rod clamped, at the same time the armature lever L. is pulled down out of its normal position and the carbon holding rod raised and the arc started.

In this way the lamp cuts itself out automatically when the arc gets too long and re-inserts itself automatically in the circuit if the carbons drop together.

It will be seen that the cut-out may be modified without departing from the spirit of my invention as long as the shunt magnet closes a circuit including a wire upon the main magnet and continues to keep the contact closed, being magnetized by magnetic induction from the main magnet.—It is also obvious to say that the magnets and armatures may be of any desired shape.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is

First. The combination in an arc-lamp, of a main and shunt magnet, an armature lever to draw the arc, a clamp and an armature to act upon the clamp, a clamping pole and a releasing pole upon the respective cores, the cores, poles, armature lever and clamping armature forming a compound magnet, substantially as set forth.

Second. The combination in an electric arc lamp, of a carbon holder and its rod, a clamp for such carbon holder, a clamping armature connected to the clamp, a compound electro-magnet controlling the action of the clamping armature, and electric circuit connections substantially as set forth for lessening the magnetism of the compound magnet when the arc between the carbons lengthens and augmenting the magnetism of the same when the arc is shortened, substantially as described.

Third. The combination with the carbon holders in an electric lamp, of a clamp around the rod of the upper carbon holder, the clamping armature connected with said clamp, the armature lever and connection from the same to the clamp, the main and shunt magnets and the respective poles of the same to act upon the clamping armature and armature lever respectively substantially as set forth.

Fourth. In an electric arc lamp, a cut-out consisting of a main magnet, an armature and a shunt magnet having an insulated pole piece, and the cut-out circuit connections through the pole piece and armature, substantially as set forth.

Fifth. In an electric arc lamp, the combination with the carbon holder and magnets, of the armatures L. and *g.* link e^1 clamp *r.* and lever *t.* and the springs s^1 for the purposes set forth.

Sixth. In an electric arc lamp the combination with two upright magnets in the main and shunt circuits respectively, having curved pole pieces on one end and converging pole pieces on the other end, of a flat Z shaped armature lever between the curved pole-pieces and a clamping armature between the convergent pole-pieces substantially as described.

Seventh. The combination in an electric arc lamp, of an electro-magnet in the main circuit and an electro-magnet in the shunt circuit, an armature under the influence of the poles of the respective magnets and circuit connections controlled by such armature to cut out or shunt the lamp substantially as specified, whereby the branch circuit is closed by the magnetism of the shunt magnet and then kept closed by induced magnetism from the main magnet, substantially as set forth.

Eighth. The combination with the carbon holder and rod and the main and shunt magnets, of a feeding clamp, an armature for the same, clamping and releasing poles upon the cores of the respective magnets and circuit connections through the clamping armature, substantially as specified for shunting the current when the arc between the carbons becomes abnormally long, substantially as set forth.

Ninth. The combination with the carbon holding rod and a clamp for the same, of an armature upon the clamp, a shunt magnet the pole of which acts to release the clamp, a main magnet with a two part helix, one portion being in the main circuit and the other portion in a shunt or cut-out circuit, the clamping armature acting to close said cut-out circuit when the arc becomes too long and to break the shunt circuit when the carbons come together, substantially as set forth.

Tenth. The combination with the carbon holders of two magnets one in the main circuit and the other in a shunt circuit and an armature lever to draw the arc and a feeding mechanism and pole-pieces upon the electro magnets to act upon the feeding mechanism substantially as specified.

Eleventh. The combination with the carbon-holders, of two magnets, one in the main circuit, and the other in a shunt circuit, an armature lever between two poles of such electro-magnets to draw the arc, pole pieces upon the other two poles of the electro-magnets, and a feeding mechanism between and acted upon by such pole pieces substantially as specified.

Twelfth. The combination with the carbon holder, of a tubular clamp surrounding the same, an armature lever connected to said tubular clamp and electro-magnets in the main and shunt circuits respectively and an armature upon the tubular clamp adjacent to the lateral poles of the electro-magnets, substantially as set forth.

Dated this 16th day of September 1886.

BREWER & SON,
For the Applicant.

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1886.

Fig. 1.

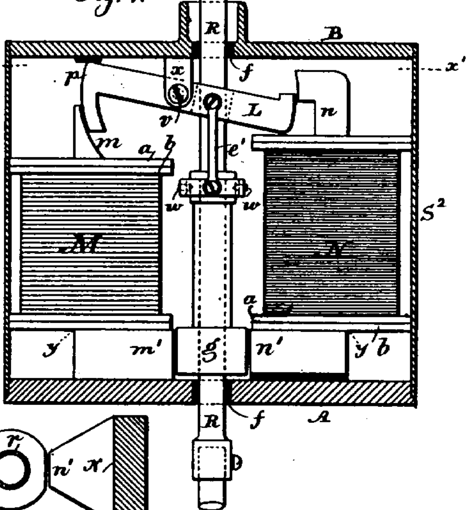


Fig. 4.

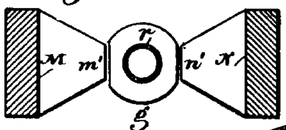


Fig. 2.

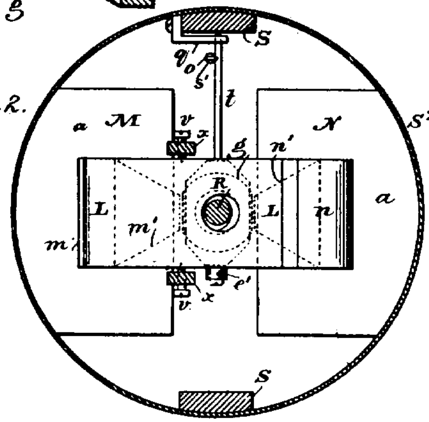


Fig. 3.

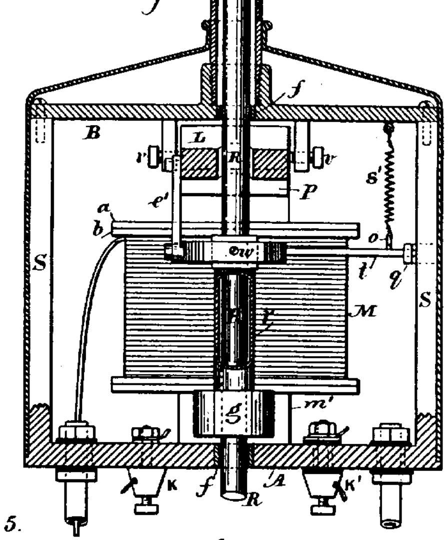


Fig. 6

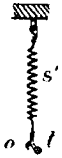


Fig. 5.

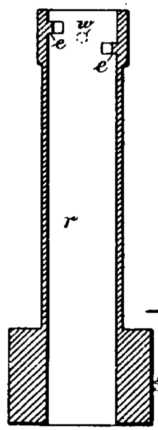
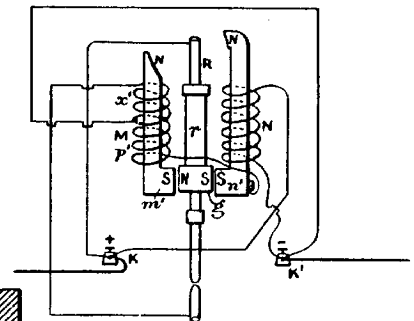


Fig. 7.



N° 2801 A.D. 1894

(*Under International Convention.*)

Date claimed for Patent under Sect. 103 of Act, being date of first Foreign Application (in United Sta'es of A erica), } *19th Aug., 1893*

Date of Application (in United Kingdom), 8th Feb., 1894

Complete Specification Left, 8th Feb., 1894—Accepted, 14th Apr., 1894

COMPLETE SPECIFICATION.

Improvements in Reciprocating Engines and Means for Regulating the Period of the same.

I, NIKOLA TESLA, of 35 South Fifth Avenue, New York, County and State of New York, United States of America, do hereby declare the nature of this invention, and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

In the invention which forms the subject of my present application, my object has been, primarily to provide an engine which under the influence of an applied force such as the elastic tension of steam or gas under pressure will yield an oscillatory movement which, within very wide limits, will be of constant period, irrespective of variations of load, frictional losses and other factors which in all ordinary engines produce change in the rate of reciprocation.

The further objects of the invention are to provide a mechanism, capable of converting the energy of steam or gas under pressure into mechanical power more economically than the forms of engine heretofore used, chiefly by overcoming the losses which result in these by the combination with rotating parts possessing great inertia of a reciprocating system; which also, is better adapted for use at higher temperatures and pressures, and which is capable of useful and practical application to general industrial purposes, particularly in small units.

The invention is based upon certain well known mechanical principles a statement of which will assist in a better understanding of the nature and purposes of the objects sought and results obtained.

Heretofore, where the pressure of steam or any gas has been utilized and applied for the production of mechanical motion it has been customary to connect with the reciprocating or moving parts of the engine a fly-wheel or some rotary system equivalent in its effect and possessing relatively great mechanical inertia, upon which dependence was mainly placed for the maintenance of constant speed. This, while securing in a measure this object, renders impossible the attainment of the result at which I have arrived, and is attended by disadvantages which by my invention are entirely obviated. On the other hand, in certain cases, where reciprocating engines or tools have been used without a rotating system of great inertia, no attempt, so far as I know, has been made to secure conditions which would necessarily yield such results as I have reached.

It is a well known principle that if a spring possessing a sensible inertia be brought under tension, as by being stretched, and then freed it will perform vibrations which are isochronous and, as to period, in the main dependent upon the rigidity of the spring, and its own inertia or that of the system of which it may form an immediate part. This is known to be true in all cases where the force which tends to bring the spring or movable system into a given position is proportionate to the displacement.

In carrying out my invention and for securing the objects in general terms stated above, I employ the energy of steam or gas under pressure acting through proper mechanism, to maintain in oscillation a piston, and, taking advantage of the law above stated, I connect with said piston, or cause to act upon it, a spring, under such conditions as to automatically regulate the period of the vibration, so that the alternate impulses of the power impelled piston, and the natural vibrations of the spring shall always correspond in direction and coincide in time.

While, in the practice of the invention I may employ any kind of spring or elastic body of which the law or principle of operation above defined holds true, I prefer to use an air spring, or generally speaking a confined body or cushion of an elastic fluid, as the mechanical difficulties in the use of ordinary or metallic springs are serious, owing mainly, to their tendency to break. Moreover, instead of permitting the piston to impinge directly upon such cushions within its own cylinder, I prefer, in order to avoid the influence of the varying pressure of the steam or gas that acts upon the piston and which might disturb the relations necessary for the maintenance of isochronous vibration, and also to better utilize the heat generated by the compression, to employ an independent plunger connected with the main piston, and a chamber or cylinder therefor, containing air which is, normally, at the same pressure as the external atmosphere, for thus a spring of practically constant rigidity is obtained but the air or gas within the cylinder may be maintained at any pressure.

In order to describe the best manner of which I am aware in which the invention is or may be carried into effect, I refer now to the accompanying drawing which represents in central cross-section an engine embodying my improvements.

A is the main cylinder in which works a piston B. Inlet ports C C pass through the sides of the cylinder, opening at the middle portion thereof and on opposite sides.

Exhaust ports D D extend through the walls of the cylinder and are formed with branches that open into the interior of the cylinder on each side of the inlet ports and on opposite sides of the cylinder.

The piston B is formed with two circumferential grooves E F, which communicate through openings G in the piston with the cylinder on opposite sides of said piston respectively.

I do not consider as of special importance the particular construction and arrangement of the cylinder, the piston and the valves for controlling it, except that it is desirable that all the ports, and more especially, the exhaust ports should be made very much larger than is usually the case, so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction.

The piston B is secured to a piston rod H, which works in suitable stuffing boxes in the heads of the cylinder A.

This rod is prolonged on one side and extends through bearing V in a cylinder I suitably mounted or supported in line with the first, and within which is a disk or plunger J carried by the rod H.

The cylinder I is without ports of any kind and is air-tight as a small leakage may occur through the bearings V, which experience has shown need not be fitted with any very considerable accuracy.

The cylinder I is surrounded by a jacket K which leaves an open space or chamber around it. The bearings V in the cylinder I, extend through the jacket K to the outside air and the chamber between the cylinder and jacket is made steam or air tight as by suitable packing.

The main supply pipe L for steam or compressed air leads into this chamber, and the two pipes that lead to the cylinder A run from the said chamber, oil cups M being conveniently arranged to deliver oil into the said pipes for lubricating the piston.

In this particular form of engine shown, the jacket K which contains the cylinder I is provided with a flange N by which it is screwed to the end of the cylinder A. A small chamber O is thus formed which has air vents P in its sides and drip pipes Q leading out from it through which the oil which collects in it is carried off.

To explain now the operation of the device above described.

In the position of the parts shown, or when the piston is at the middle point of its stroke, the plunger J is at the centre of the cylinder I and the air on both sides of the same is at the normal pressure of the outside atmosphere. If a source of steam or compressed air be then connected to the inlet ports C C of the cylinder A and a movement be imparted to the piston as by a sudden blow, the latter is caused to reciprocate in a manner well understood. The movement of the piston in either direction ceases when the force tending to impel it and the momentum which it has acquired are counterbalanced by the increasing pressure of the steam or compressed air in that end of the cylinder towards which it is moving and as in its movement the piston has shut off at a given point, the pressure that impelled it and established the pressure that tends to return it, it is then impelled in the opposite direction, and this action is continued as long as the requisite pressure is applied.

The movements of the piston compress and rarify the air in the cylinder I at opposite ends of the same alternately. A forward stroke compresses the air ahead of the plunger J which acts as a spring to return it, similarly on the back stroke the air is compressed or the opposite side of the plunger J and tends to drive it forward.

The compressions of the air in the cylinder I and the consequent loss of energy due mainly to the imperfect elasticity of the air, give rise to a very considerable amount of heat. This heat I utilize by conducting the steam or compressed air to the engine cylinder through the chamber formed by the jacket surrounding the air-spring cylinder, the heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine.

In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above or the reduction of pressure below the normal.

In constructing the apparatus I allow for a variation in the length of stroke by giving to the confining cylinder I of the air spring properly determined dimensions. The greater the pressure upon the piston, the higher will be the degree of compression of the air-spring, and the consequent counteracting force upon the plunger.

The rate or period of reciprocation of the piston however is no more dependent upon the pressure applied to drive it, than would be the period of oscillation of a pendulum permanently maintained in vibration, upon the force which periodically impels it, the effect of variations in such force being merely to produce corresponding variations in the length of stroke or amplitude of vibration respectively. The period is mainly determined by the rigidity of the air spring and the inertia of the moving system, and I may therefore secure any period of oscillation within very wide limits by properly portioning these factors, as by varying the dimensions of the air chamber which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts.

These conditions are all readily determinable, and an engine constructed as herein described may be made to follow the principle of operation above stated and maintain a perfectly uniform period through very much wider limits of pressure than in ordinary use, it is ever likely to be subjected to and it may be successfully used as a prime mover wherever a constant rate of oscillation or speed is required, provided the limits within which the forces tending to bring the moving system to a given position are proportionate to the displacements, are not materially exceeded.

The pressure of the air confined in the cylinder when the plunger I is in its central position will always be practically that of the surrounding atmosphere, for while the cylinder is so constructed as not to permit such sudden escape of air as to sensibly impair or modify the action of the air spring there will still be a slow leakage of air into or out of it around the piston rod according to the pressure therein, so that the pressure of the air on opposite sides of the plunger will always tend to remain at that of the outside atmosphere.

As an instance of the uses to which this engine may be applied I have shown its piston rod connected with a pawl R the oscillation of which desires a train of wheels. These may constitute the train of a clock or of any other mechanism. Another application of the invention is to move a conductor in a magnetic field for generating electric currents, and in these and similar uses it is obvious that the characteristics of the engine render it specially adapted for use in small sizes or units.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is

1. A reciprocating engine comprising a cylinder and piston, and a spring connected with or acting upon the reciprocating element combined and related in substantially the manner described so that the forces which tend to bring the reciprocating parts into a given position are proportionate to the displacements whereby an isochronous vibration is obtained.

2. A reciprocating engine comprising a cylinder and a piston impelled by steam or gas under pressure and an air-spring maintained in vibration by the movements of the piston, combined and related in substantially the manner described so that the forces which tend to bring the reciprocating parts into a given position are proportionate to the displacements whereby an isochronous vibration is obtained.

3. The combination of a cylinder and a piston adapted to be reciprocated by steam or gas under pressure, a cylinder and a plunger therein reciprocated by the piston and constituting with its cylinder an air spring adapted to maintain the piston in reciprocation at a defined rate or period as set forth.

4. The combination of a cylinder and a piston adapted to be reciprocated by steam or gas under pressure, a cylinder and piston constituting an air spring connected with the piston, a jacket forming a chamber around the air spring through which the steam or compressed gas is passed on its way to the cylinder, as and for the purpose set forth.

5. The method of producing isochronous movement herein described, which consists in reciprocating a piston by steam or gas under pressure and controlling the rate or period of reciprocation by the vibration of a spring, as set forth.

6. The method of operating a reciprocating engine which consists in reciprocating a piston, maintaining by the movements of the piston, the vibration of an air spring and applying the heat generated by the compression of the spring to the steam or gas driving the piston.

Dated the 16th day of January 1894.

NIKOLA TESLA.

Haseltine, Lake & Co.,
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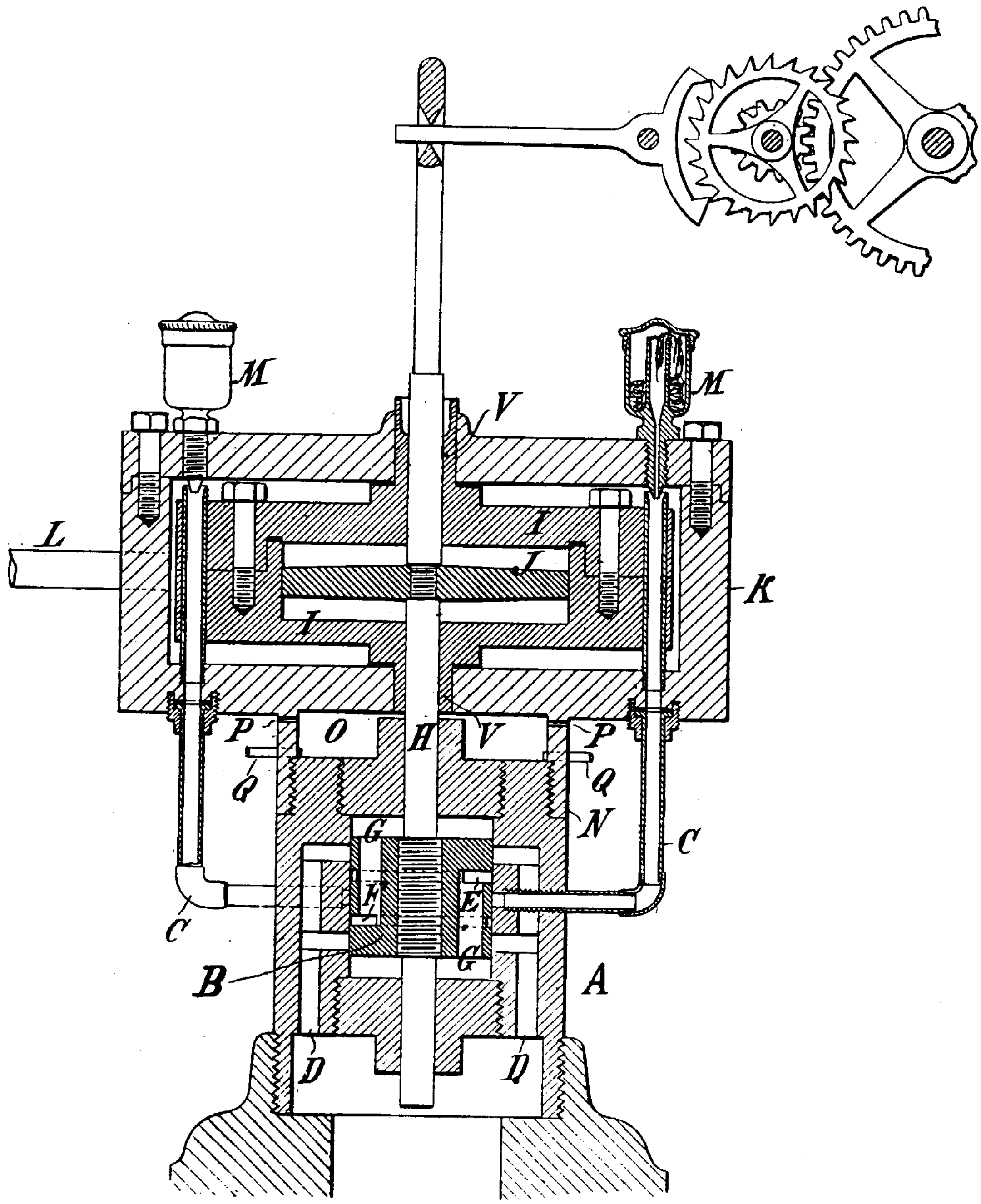
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Date of Application (in United Kingdom), 8th Feb., 1894

Complete Specification Left, 8th Feb., 1894—Accepted, 10th Mar., 1894

COMPLETE SPECIFICATION.

Improvements in Methods of and Apparatus for the Generation of Electric Currents of Defined Period.

I, NIKOLA TESLA, of 35 South Fifth Avenue, New York, County and State of New York, United States of America, Electrician, do hereby declare the nature of this invention, and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

This invention consists in producing electric currents of constant period by means of an engine and an electrical generator which are so constructed and related that (*a*), the engine of itself is capable of imparting to the moving element of the generator an oscillation of constant period, or (*b*) the period of reciprocation of the engine and the natural rate of vibration of the electric system will so nearly approximate as to act in resonance, or, (*c*), the engine, while fully capable of maintaining a vibration once started has not the power to change its rate so that the electric system will entirely control its period.

A description of the engine proper which has the property of running with a constant period is necessary to a complete understanding of the present invention. The following conditions are to be observed in order to produce such an engine.

It is a well known mechanical principle that if a spring possessing a sensible inertia be brought under tension, as by being stretched, and then freed, it will perform vibrations which are isochronous, and, as to period, in the main, dependent upon the rigidity of the spring, and its own inertia or that of the system of which it may form an immediate part. This is known to be true in all cases where the force which tends to bring the spring or movable system into a given position is proportionate to the displacement.

In the construction of the engine above referred to this principle is followed, that is to say, a cylinder and a piston are used one or both of which in any suitable manner are maintained in reciprocation by steam or gas under pressure. To the moving piston or to the cylinder in case the latter reciprocate and the piston remain stationary, a spring is connected so as to be maintained in vibration thereby, and whatever may be the inertia of the piston or of the moving system and the rigidity of the spring relatively to each other, provided the practical limits within which the law holds true that the forces which tend to bring the moving system to a given position are proportionate to the displacement, are not exceeded, the impulses of the power impelled piston and the natural vibrations of the spring will always correspond in direction and coincide in time.

In the case of the engine referred to, the parts are so arranged that the movement of the piston within the cylinder in either direction ceases when the force tending to impel it and the momentum which it has acquired are counterbalanced by the increasing pressure of the steam or compressed air in that end of the cylinder towards which it is moving, and as in its movement the piston has shut off, at a given point, the pressure that impelled it and established the pressure that tends to return it, it is then impelled in the opposite direction, and this action is continued as long as the requisite pressure is applied. The length of the stroke will vary with the pressure, but the rate or period of reciprocation is no more dependent upon the pressure applied to drive the piston, than would be the period of oscillation of, a pendulum permanently maintained in vibration, upon the force which periodically impels it, the effect of variations in such force being merely to produce corresponding variations in the length of stroke or amplitude of vibration respectively.

In practice I have found that the best results are secured by the employment of an air spring, that is, a body of confined air or gas which is compressed and rarefied by the movements of the piston, and in order to secure a spring of constant rigidity I prefer to employ a separate chamber or cylinder containing air at the normal atmospheric pressure, although it might be at any other pressure, and in which works a plunger connected with or carried by the piston rod. The main reason why no engine heretofore has been capable of producing results of this nature is that it has been customary to connect with the reciprocating parts a heavy fly-wheel or some equivalent rotary system of relatively very great inertia, or in other cases where no rotary system was employed, as in certain reciprocating engines or tools, no regard has been paid to the obtainment of the conditions essential to the end which I have in view, nor would the presence of such conditions in said devices appear to result in any special advantage.

Such an engine as I have described affords a means of accomplishing a result heretofore unattained, the continued production of electric currents of constant period, by imparting the movements of the piston to a core or coil in a magnetic field.

It should be stated, however, that in applying the engine for this purpose certain conditions are encountered which should be taken into consideration in order to satisfactorily secure the desired result. When a conductor is moved in a magnetic field and a current caused to circulate therein, the electro-magnetic reaction between it and the field, might disturb the mechanical oscillation to such an extent as to thrown it out of isochronism. This, for instance, might occur when the electro-magnet reaction is very great in comparison to the power of the engine, and there is a retardation of the current so that the electro-magnetic reaction might have an effect similar to that which would result from a variation of the tension of the spring but, if the circuit of the generator be so adjusted that the phases of the electromotive force and current coincide in time, that is to say, when the current is not retarded then the generator driven by the engine acts merely as a frictional resistance and will not, as a rule, alter the period of the mechanical vibration, although it may vary its amplitude. This condition may be readily secured by properly proportioning the self-induction and capacity of the circuit including the generator.

I have, however, observed the further fact in connection with the use of such engines as a means for running a generator, that it is advantageous that the period of the engine and the natural period of electrical vibration of the generator should be the same, as in such case the best conditions for electric resonance are established and the possibility of disturbing the period of mechanical vibrations is reduced to a minimum. So much so that I have found that even if the theoretical conditions necessary for maintaining a constant period in the engine itself are not exactly maintained, still the engine and generator combined will vibrate at a constant period. For example, if instead of using in the engine an independent cylinder and plunger as an air spring of practically constant rigidity, I cause the piston to impinge upon air cushions at the ends of its own cylinder, although the rigidity of such cushions or springs might be considerably affected and varied by the variations of pressure within the cylinder, still by combining with such an engine a generator which has a period of its own approximately that of the engine, constant vibration may be maintained even through a considerable range of varying pressure, owing to the controlling action of the electro-magnetic system.

I have even found that under certain conditions the influence of the electro-magnetic system may be made so great as to entirely control the period of the mechanical vibration within wide limits of varying pressure.

This is likely to occur in those instances where the power of the engine while fully capable of maintaining a vibration once started, is not sufficient to change its rate.

So, for sake of illustration, if a pendulum is started in vibration, and a small force applied periodically in the proper direction to maintain it in motion, this force would have no substantial control over the period of the oscillation unless the inertia of the pendulum be small in comparison to the impelling force, and this would be true no matter through what fraction of the period the force may be applied.

In the case under consideration the engine is merely an agent for maintaining the vibration once started, although it will be understood that this does not preclude the performance of useful work which would simply result in a shortening of the stroke.

My invention, therefore, involves the combination of a piston free to reciprocate under the influence of a steam or a gas under pressure and the movable element of an electric generator which is in direct mechanical connection with the piston, and it is, more especially the object of my invention to secure from such combination electric currents of a constant period. In the attainment of this object I have found it is preferable to construct the engine so that it of itself controls the period, but as I have stated before, I may so modify the elements of the combination that the electro-magnetic system may exert a partial or even complete control of the period.

In illustration of the manner in which the invention is carried out I now refer to the accompanying drawings:

Fig. 1 is a central sectional view of an engine and generator embodying the invention.

Fig. 2 is a modification of the same.

Referring to Figure 1, A is the main cylinder in which works a piston B. Inlet ports C C pass through the sides of the cylinder opening at the middle portion thereof and on opposite sides.

Exhaust ports D D extend through the walls of the cylinder and are formed with branches that open into the interior of the cylinder on each side of the inlet ports and on opposite sides of the cylinder.

The piston B is formed with two circumferential grooves E F which communicate through openings G in the piston with the cylinder on opposite sides of said piston respectively.

The particular construction of the cylinder, the piston and the valves for controlling it may be very much varied, and it is not in itself material, except that in the special case now under consideration it is desirable that all the ports, and more especially the exhaust ports should be made very much larger than is usually the case so that no force due to the action of the steam or compressed air will tend to retard or affect the return of the piston in either direction.

The piston B is secured to a piston rod H which works in suitable stuffing boxes in the heads of the cylinder A.

This rod is prolonged on one side and extends through bearings V in a cylinder I suitably mounted or supported in line with the first, and within which is a disk or plunger J carried by the rod H.

The cylinder I is without ports of any kind and is air-tight, except as a small leakage may occur through the bearings V, which experience has shown need not be fitted with any very considerable accuracy.

The cylinder I is surrounded by a jacket K which leaves an open space or chamber around it. The bearings V in the cylinder I, extend through the jacket K to the outside air and the chamber between the cylinder and jacket is made steam or air tight as by suitable packing.

The main supply pipe L for steam or compressed air leads into this chamber, and the two pipes that lead to the cylinder A run from the said chamber, oil cups M being conveniently arranged to deliver oil into the said pipes for lubricating the piston.

In the particular form of engine shown, the jacket K which contains the cylinder I is provided with a flange N by which it is screwed to the end of the cylinder A. A small chamber O is thus formed which has air vents P in its sides and drip pipes Q leading out from it through which the oil which collects in it is carried off.

To explain now the operation of the engine described:

In the position of the parts shown, or when the piston is at the middle point of its stroke, the plunger J is at the center of the cylinder I and the air on both sides of the same is at the normal pressure of the outside atmosphere. If a source of steam or compressed air be then connected to the inlet ports C C of the cylinder A and a movement be imparted to the piston as by a sudden blow, the latter is caused to reciprocate in a manner well understood.

The movements of the piston compress and rarefy the air in the cylinder I at opposite ends of the same alternately. A forward stroke compresses the air ahead of the plunger J which acts as a spring to return it, similarly on the back stroke the air is compressed on the opposite side of the plunger J and tends to drive it forward.

The compressions of the air in the cylinder I and the consequent loss of energy due mainly to the imperfect elasticity of the air, give rise to a very considerable amount of heat. This heat I utilize by conducting the steam or compressed air to the engine cylinder through the chamber formed by the jacket surrounding the air-spring cylinder. The heat thus taken up and used to raise the temperature of the steam or air acting upon the piston is availed of to increase the efficiency of the engine.

In any given engine of this kind the normal pressure will produce a stroke of determined length, and this will be increased or diminished according to the increase of pressure above or the reduction of pressure below the normal.

In constructing the apparatus proper allowance is made for a variation in the length of stroke by giving to the confining cylinder I of the air spring properly determined dimensions. The greater the pressure upon the piston, the higher will be the degree of compression of the air-spring, and the consequent counteracting force upon the plunger.

The rate or period of reciprocation of the piston however, is mainly determined, as above set forth, by the rigidity of the air spring and the inertia of the moving system, and any period of oscillation within very wide limits may be secured by properly proportioning these factors, as by varying the dimensions of the air chamber which is equivalent to varying the rigidity of the spring, or by adjusting the weight of the moving parts.

These conditions are all readily determinable, and an engine constructed as herein described may be made to follow the principle of operation above stated and maintain a perfectly uniform period through very wide limits of pressure.

The pressure of the air confined in the cylinder when the plunger I is in its central position will always be practically that of the surrounding atmosphere, for while the cylinder is so constructed as not to permit such sudden escape of air as to sensibly impair or modify the action of the air spring there will still be a slow leakage of the air into or out of it around the piston rod according to the pressure therein, so that the pressure of the air on opposite sides of the plunger will always tend to remain at that of the outside atmosphere.

To the piston rod H is secured a conductor or coil of wire D^1 which by the movements of the piston is oscillated in the magnetic field produced by two magnets B^1 B^1 which may be permanent magnets or energized by coils C^1 C^1 connected with a source of continued currents E^1. The movement of the coil D^1 across the lines of force established by the magnets gives rise to alternating currents in the coil. These currents, if the period of mechanical oscillation be constant will be of constant period, and may be utilized for any purpose desired.

In the case under consideration it is assumed as a necessary condition that the inertia of the movable element of the generator and the electro-magnetic reaction which it exerts will not be of such character as to materially disturb the action of the engine.

Fig. 2 is an example of a combination in which the engine is not of itself capable of determining entirely the period of oscillation, but in which the generator contributes to this end. In this figure the engine is the same as in Fig. 1. The exterior air spring is however omitted and the air space at the ends of the cylinder A relied on for accomplishing the same purpose. As the pressure in these spaces is liable to variations from variations in the steam or gas used in impelling the piston they might affect the period of oscillation, and the conditions are not as stable and certain as in the case of an engine constructed as in Fig. 1. But if the natural period of vibration of the electric system be made to approximately accord with the average period of the engine, such tendencies to variation are very largely overcome and the engine will preserve its period even through a considerable range of variations of pressure.

The generator in this case is composed of a magnetic casing F^1 in which a laminated core G^1 secured to the piston rod H is caused to vibrate. Surrounding the plunger are two exciting coils C^1 C^1, and one or more induced coils D^1 D^1.

The coils C^1 C^1 are connected with a generator of continuous currents E^1 and are wound to produce consequent poles in the core G^1. Any movement of the latter will therefore shift the lines of force through coils D^1 D^1 and produce currents therein.

In the circuit of coils D^1 is shown a condenser H^1. It need only be said that by the use of a proper condenser the self-induction of this circuit may be neutralized. Such a circuit will have a certain natural period of vibration, that is to say that when the electricity therein is disturbed in any way an electrical vibration of a certain period takes place, and as this depends upon the capacity and self-induction, such period may be varied to approximately accord with the period of the engine.

In case the power of the engine be comparatively small as when the pressure is applied through a very small fraction of the total stroke, the electrical vibration will tend to control the period, and it is clear that if the character of such vibration be not very widely different from the average period of vibration of the engine under ordinary working conditions that such control may be entirely adequate to produce the desired results.

It is evident that when a conductor in a magnetic field or a magnetic core, is vibrated by mechanism such as is here described the character of the current impulses developed will vary according to existing conditions, as for example, the current impulses may lag behind the electro motive impulses more or less, and from this it may result that the positive and negative impulses in certain cases may differ in electro-motive force, or the degree of saturation of the core may modify the character of the currents. Thus it is possible in such apparatus, as I have described, to secure a preponderance of the electro-motive impulses of one direction over those in the other, and by a proper observance of these conditions I am able to produce effects similar to those produced by unidirectional currents.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:

1. The combination with the piston or equivalent element of an engine which is free to reciprocate under the action thereon of steam or a gas under pressure, of the moving conductor or element of an electric generator in direct mechanical connection therewith.

2. The combination with the piston or equivalent element of an engine which is

free to reciprocate under the action of steam or a gas under pressure, of the moving conductor or element of an electric generator in direct mechanical connection therewith, the engine and generator being adapted by their relative adjustment with respect to period to produce currents of constant period, as set forth.

3. The combination with an engine comprising a piston free to reciprocate under the action of steam or a gas under pressure, and an electric generator composed of field magnets or coils and a core or conductor capable of oscillation in the field produced thereby, the said core or conductor being carried by the piston rod of the engine as set forth.

4. The combination with an engine operated by steam or a gas under pressure and having a constant period of reciprocation, of an electric generator, the moving conductor or element of which is connected with the engine, the generator and its circuit being so related to the engine as not to disturb its period as set forth.

5. The combination with a cylinder and a piston reciprocated by steam or a gas under pressure of a spring maintained in vibration by the movement of the piston, and an electric generator, the movable conductor or element of which is connected with the piston, these elements being constructed and adapted in the manner set forth for producing a current of constant period.

6. The method of producing electric currents of constant period herein described which consists in imparting the oscillations of an engine to the moving element of an electric generator and regulating the period of mechanical oscillation by an adjustment of the reaction of the electric generator, as herein set forth.

Dated the 16th day of January 1894.

NIKOLA TESLA.

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Fig. 1

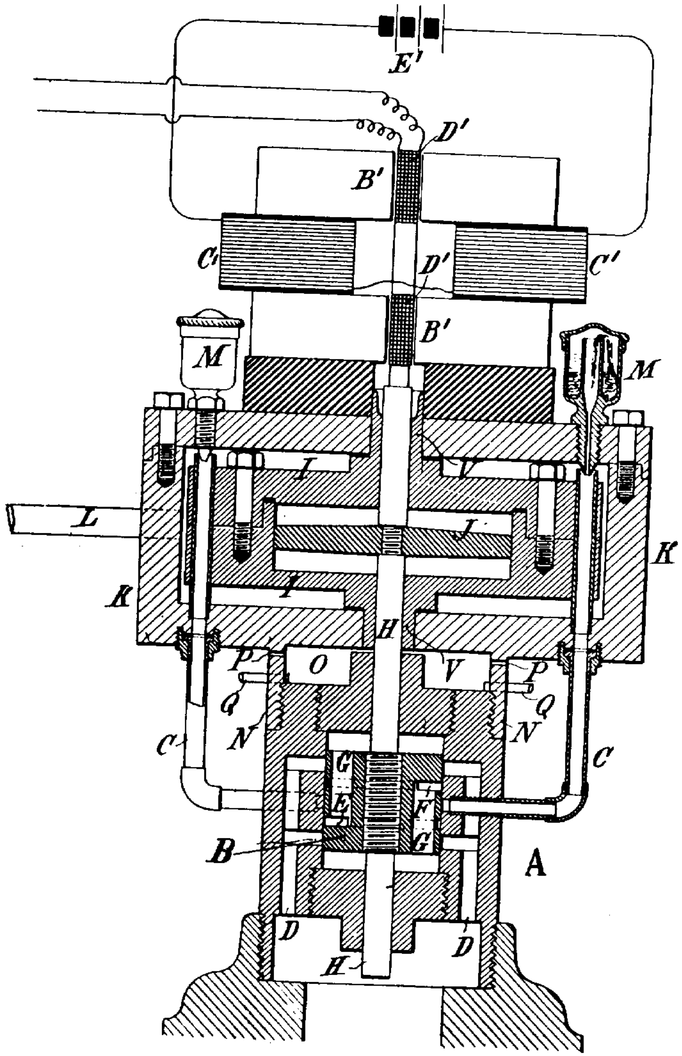
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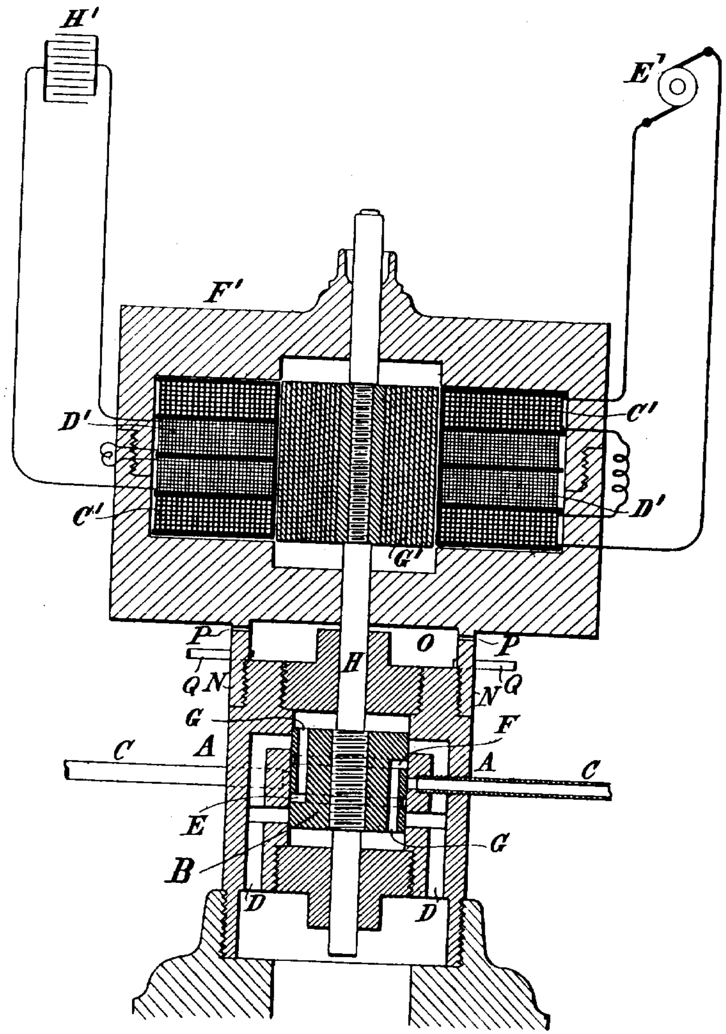
Fig. 2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Date of Application, 2nd Mar., 1886.
Complete Left, 31st Dec., 1886.
Complete Accepted, 1st Feb., 1887.

A.D. 1886, *2nd March.* N° 2975.

PROVISIONAL SPECIFICATION.

Improvements in Dynamo Electric Machines.

I Nikola Tesla, formerly of Smiljan Lika, Border country of Austro-Hungary, now residing on Main Street, Rahway, State of New Jersey, United States of America, Electrician do hereby declare the nature of this invention to be as follows:—

The object of my invention is to provide an improved method for regulating the current on dynamo electric machines.

In my improvements I make use of two main brushes to which the ends of the helices of the field magnets are connected and an auxiliary brush and a branch or shunt connection from an intermediate point of the field wire to the auxiliary brush. The relative positions of the respective brushes are varied either automatically or by hand, so that the shunt becomes in-operative when the auxiliary brush has a certain position upon the commutator, but when said auxiliary brush is moved in its relation to the main brushes or the latter are moved in their relation to the auxiliary brush, the electric condition is disturbed and more or less of the current through the field helices is diverted through the shunt, or a current passed over said shunt to the field helices. By varying the relative position upon the commutator of the respective brushes automatically in proportion to the varying electrical condition of the working circuit the current developed can be regulated in proportion to the demands in the working circuit.

Devices for automatically moving the brushes in dynamo electric machines are well known, and those made use of in my machine may be of any desired or known character.

Figure 1 of the accompanying drawings is a diagram illustrating my invention showing one core of the field magnets with one helix wound in the same direction throughout.

Figures 2 and 3 are diagrams showing one core of the field magnets with a portion of the helices wound in opposite directions.

Figures 4 and 5 are diagrams illustrating the electric devices that may be employed for automatically adjusting the brushes.

Figure 6 is a diagram illustrating the positions of the brushes when the machine is being energised on the start.

Figures 7, 8, 9, 10 and 11 are diagrams that further illustrate my invention as hereafter described.

a, and *b* are positive and negative brushes of the main or working circuit, and *c* the auxiliary brush. The working circuit D extends from the brushes *a* and *b* as usual and contains electric lamps or other devices D^1—either in series or in multiple arc.

M, M^1 represent the field helices, the ends of which are connected to the main brushes *a* and *b*.

The branch or shunt wire c^1 extends from the auxiliary brush *c* to the circuit of the field helices and is connected to the same at an intermediate point *x*. H represents the commutator with the plates of ordinary construction.

It is now to be understood that when the auxiliary brush *c* occupies such a position upon the commutator that the electro-motive force between the brushes *a* and *c* is to the electro motive force between the brushes *c* and *b* as the resistance of the circuit *a*, M, c^1, *c*, A to the resistance of the circuit *b*, M^1, c^1, *c*, B the potentials of the points *x* and *y* will be equal and no current will flow over the auxiliary brush, but when the brush *c* occupies a different position, the potentials of the points *x* and *y* will be different and a current will flow over the auxiliary brush to or from the commutator, according to the relative position of the brushes. If for instance the commutator space between the brushes *a* and *c*, when the latter is at the neutral point, is diminished, a current will flow from the point *y* over the shunt *c* to the brush *b* thus strengthening the current in the part M^1, and partly neutralizing the current in the part M; but if the space between the brushes *a* and *c* is increased, the current will flow over the auxiliary brush in an opposite direction and the current in M will be strengthened and in M^1 partly neutralized. By combining with the brushes *a b* and *c* any known automatic regulating mechanism, the current developed can be regulated in proportion to the demands in the working circuit.

The parts M and M^1 of the field wire may be wound in the same direction (in this case they are arranged as shown in Figure 1 or the part M may be wound in the opposite direction as shown in Figures 2 and 3).

It will be apparent that the respective cores of the field magnets are subjected to the neutralizing or intensifying effects of the current in the shunt through c^1 and the magnetism of the cores will be partially neutralized or the point of greatest magnetism shifted, so that it will be more or less remote from or approaching to, the armature and hence the aggregate energizing actions of the field magnets on the armature will be correspondingly varied. In the form indicated in Figure 1 the regulation is effected by shifting the point of greatest magnetism, and in Figures 2 and 3 the same effect is produced by the action of the current in the shunt passing through the neutralizing helix.

In Figures 4 and 5, A^1, A^1, indicate the main brush holder carrying the main brushes, and C the auxiliary brush holder carrying the auxiliary brush. These brush holders are movable in arcs concentric with the centre of the commutator shaft.

An iron piston P of the solenoid S, (Figure 4) is attached to the auxiliary brush holder C. The adjustment is effected by means of a spring and screw or tightener.

In Figure 5 instead of a solenoid an iron tube enclosing a coil is shown. The piston P of the coil is attached to both brush holders A^1, A^1, and C. When the brushes are moved directly by electrical devices as shown in Figures 4 and 5, these are so constructed that the force exerted for adjusting is practically uniform through the whole length of motion.

The relative positions of the respective brushes may be varied by moving the auxiliary brush or the brush *c* may remain quiescent and the core *p* be connected to the main brush holder A^1, so as to adjust the brushes *a*, *b*, in their relation to the brush *c*. If however an adjustment is applied to all the brushes as seen in Figure 5 the solenoid should be connected to both A^1, and C so as to move them towards or away from each other. There are several known devices for giving motion in proportion to an electric current. I have shown the moving cores in Figures 4 and 5, as convenient devices for obtaining the required extent of motion with very slight changes in the current passing through the helices.

It is understood that the adjustment of the main brushes causes variations in the strength of the current independently of the relative position of said brushes to the auxiliary brush. In all cases the adjustment may be such that no current flows over the auxiliary brush when the dynamo is running with its normal load.

I am aware that auxiliary brushes have been used in connection with the helices of the field wire, but in these instances the helices received the entire current through the auxiliary brush or brushes and said brushes could not be taken off without breaking the current through the field. These brushes caused however a great sparking upon the commutator. In my improvements the auxiliary brush causes very little or no sparking and can be taken off without breaking the current through the field helices.

My improvements have, besides the advantage to facilitate the self exciting of the machine in all cases where the resistance of the field wire is very great comparatively to the resistance of the main circuit at the start, for instance on arc-light machines. In this case I place the auxiliary brush *c*, near to or in preference in contact with the brush *b*, as shown in Figure 6. In this manner the part M^1 Figures 1, 2 and 3 is completely cut out, and as the part M has a considerably smaller resistance than the whole length of the field wire the machine excites itself, whereupon the auxiliary brush is shifted automatically to its normal position.

In Figures 7, 8, 9, 10 and 11 which further illustrate my invention; *a* and *b* are the positive and negative brushes of the main circuit, and *c* an auxiliary brush. The main circuit D extends from the brushes *a* and *b*, as usual and contains the helices M of the field wire, and the electric lamps or other working devices D^1. The auxiliary brush *c* is connected to the point *x* of the main circuit by means of the wire c^1. H is a commutator of ordinary construction. When the electro motive force between the brushes *a* and *c* is to the electro-motive force between the brushes *c* and *b*, as the resistance of the circuit *a*, M, c^1, *c*, A, to the resistance of the circuit *b*, B, *c*, c^1, D, the potentials of the points *x* and *y* will be equal and no current will pass over the auxiliary brush *c* but if said brush occupies a different position relatively to the main brushes, the electric condition is disturbed and current will flow either from *y* to *x* or from *x* to *y* according to the relative position of the brushes. In the first case the current through the field helices will be partly neutralized and the magnetism of the field magnets diminished, in the second case the current will be increased and the magnets will gain strength. By combining with the brushes *a*, *b*, *c* any automatic regulating mechanism the current developed can be regulated automatically in proportion to the demands in the working circuit. In practice it is sufficient to move only the auxiliary brush as shown in Figure 4 as the regulator is very sensitive to the slightest changes, but the relative position of the auxiliary brush to the main brushes may be varied by moving the main brushes or both main and auxiliary brushes may be moved as illustrated in Figure 5. In the latter two cases it will be understood the motion of the main brushes relatively to the neutral line of the machine, causes variations in the strength of the current independently of their relative position to the auxiliary brush. In all cases the adjustment may be such that when the machine is running with the ordinary load, no current flows over the auxiliary brush.

The field helices may be connected as shown in Figure 7 or a part of the field helices may be in the outgoing, and the other part in the return circuit and two auxiliary brushes may be employed as shown in Figures 9 and 10. Instead of shunting the whole of the field helices a portion only of such helices may be shunted as shown in Figures 8 and 10.

The arrangement shown in Figure 10 is advantageous as it diminishes the sparking upon the commutator, the main circuits being closed through the auxiliary brushes at the moment of the break of the circuit at the main brushes.

The field helices may be wound in the same direction or a part may be wound in opposite directions.

The connection between the helices and the auxiliary brush or brushes may be made by a wire of small resistance, or a resistance may be interposed (R, Figure 11) between the point *x* and the auxiliary brush or brushes to divide the sensitiveness when the brushes are adjusted.

BREWER & SON,
For the Applicant.

COMPLETE SPECIFICATION.

Improvements in Dynamo Electric Machines.

I, Nikola Tesla, formerly of Smiljan Lika, border country of Austro-Hungary, now residing on Main Street, Rahway, State of New Jersey, United States of America, Electrician do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement :—

The object of my invention it to provide an improved method for regulating the current on dynamo electric machines.

In my improvement I make use of two main brushes to which the ends of the helices of the field magnets are connected and an auxiliary brush and a branch or shunt connection from an intermediate point of the field wire to the auxiliary brush. The relative positions of the respective brushes are varied either automatically or by hand, so that the shunt becomes inoperative when the auxiliary brush has a certain position upon the commutator ; but when said auxiliary brush is moved in its relation to the main brushes or the latter are moved in their relation to the auxiliary brush, the electric condition is disturbed and more or less of the current through the field helices is diverted through the shunt, or a current passed over said shunt to the field helices.

By varying the relative position upon the commutator of the respective brushes automatically in proportion to the varying electrical condition of the working circuit, the current developed can be regulated in proportion to the demands in the working circuit.

Devices for automatically moving the brushes in dynamo electric machines are well known and those made use of in my machine may be of any desired or known character.

In the drawing

Fig. 1. is a diagram illustrating my invention showing one core of the field magnets with one helix wound in the same direction throughout.

Figs. 2. and 3. are diagrams showing one core of the field magnets with a portion of the helices wound in opposite directions.

Figs. 4. and 5. are diagrams illustrating the electric devices that may be employed for automatically adjusting the brushes and

Fig. 6. is a diagram illustrating the positions of the brushes when the machine is being energized on the start.

Figs. 7. 8. 9. 10. and 11. are diagrams that further illustrate my invention as hereafter described.

a. and *b.* are positive and negative brushes of the main or working circuit and *c.* the auxiliary brush. The working circuit D. extends from the brushes *a.* and *b.* as usual and contains electric lamps or other devices D^1 either in series or in multiple arc. M. M^1 represent the field helices, the ends of which are connected to the main brushes *a.* and *b.* The branch or shunt wire c^1 extends from the auxiliary brush *c.* to the circuit of the field helices and is connected to the same at an intermediate point *x.* H. represents the commutator with the plates of ordinary construction.

It is now to be understood that when the auxiliary brush *c.* occupies such a position upon the commutator that the electro motive force between the brushes *a* and *c.* is to the electro-motive force between the brushes *c.* and *b.* as the resistance of the circuit *a.* M. c^1. *c.* A. to the resistance of the circuit *b.* M^1. c^1. *c.* B. the potentials of the points *x.* and *y.* will be equal and no current will flow over the auxiliary brush, but when the brush *c.* occupies a different position, the potentials of the points *x.* and *y.* will be different and a current will flow over the auxiliary brush to or from the commutator, according to the relative position of the brushes. If for instance the commutator space between the brushes *a.* and *c.* when the latter is at the neutral point, is diminished, a current will flow from the point *y.* over the shunt c^1 to the brush *b.* thus strengthening the current in the part M^1 and partly neutralizing the current in the part M: but if the space between the brushes *a.* and *c.* is increased, the current will flow over the auxiliary brush in an opposite direction and the current in M. will be strengthened and in M^1 partly neutralized. By combining with the brushes a. *b.* and *c.* any known automatic regulating mechanism, the current developed can be regulated in proportion to the demands in the working circuit.

The parts M and M^1 of the field wire may be wound in the same direction; in this case they are arranged as shown in fig. 1. or the part M. may be wound in the opposite direction as shown in figs. 2. and 3.

It will be apparent that the respective cores of the field magnets are subjected to the neutralizing or intensifying effects of the current in the shunt through c^1 and the magnetism of the cores will be partially neutralized or the point of greatest magnetism shifted so that it will be more or less remote from or approaching to the armature, and hence the aggregate energizing actions of the field magnets on the armature will be correspondingly varied.

In the form indicated in fig. 1. the regulation is effected by shifting the point of greatest magnetism, and in figs. 2. and 3. the same effect is produced by the action of the current in the shunt passing through the neutralizing helix.

In figs. 4. and 5. A^1 A^1 indicate the main brush holder carrying the main brushes, and C. the auxiliary brush holder carrying the auxiliary brush. These brush holders are movable in arcs concentric with the center of the commutator shaft.

An iron piston P. of the solenoid S. fig. 4. is attached to the auxiliary brush holder C. The adjustment is effected by means of a spring and screw or tightener.

In fig. 5. instead of a solenoid an iron tube inclosing a coil is shown. The piston P of the coil is attached to both brush holders A^1 A^1 and C. When the brushes are moved directly by electrical devices as shown in figs. 4 and 5. these are so constructed that the force exerted for adjusting is practically uniform through the whole length of motion.

The relative positions of the respective brushes may be varied by moving the auxiliary brush or the brush C. may remain quiescent and the core P. be connected to the main brush holder A^1 so as to adjust the brushes *a.* *b.* in their relation to the brush *c.* If, however, an adjustment is applied to all the brushes as seen in fig. 5. the solenoid should be connected to both A^1 and C. so as to move them towards or away from each other. There are several known devices for giving motion in proportion to an electric current. I have shown the moving cores in figs. 4. and 5. as convenient devices for obtaining the required extent of motion with very slight changes in the current passing through the helices.

It is understood that the adjustment of the main brushes causes variations in the strength of the current independently of the relative position of said brushes to the auxiliary brush.

In all cases the adjustment may be such that no current flows over the auxiliary brush when the dynamo is running with its normal load.

I am aware that auxiliary brushes have been used in connection with the helices of the field wire, but in these instances the helices received the entire current through the auxiliary brush or brushes and said brushes could not be taken off without breaking the current through the field. These brushes, however, caused a great sparking upon the commutator. In my improvement the auxiliary brush causes very little or no sparking and can be taken off without breaking the current through the field helices.

My improvement has besides the advantage to facilitate the self exciting of the machine in all cases where the resistance of the field wire is very great comparatively to the resistance of the main circuit at the start, for instance on arc-light machines. In this case I place the auxiliary brush *c.* near to or in preference in contact with the brush *b.* as shown in fig. 6. In this manner the part M^1 figs. 1. 2. & 3. is completely cut out, and as the part M. has a considerably smaller resistance than the whole length of the field wire, the machine excites itself, whereupon the auxiliary brush is shifted automatically to its normal position.

In figs. 7. 8. 9. 10 & 11, which further illustrates my invention, *a.* and *b.* are the positive and negative brushes of the main circuit, and *c.* an auxiliary brush. The main circuit D. extends from the brushes *a.* and *b.* as usual and contains the helices M. of the field wire and the electric lamps or other working devices D^1. The auxiliary brush *c.* is connected to the point *x.* of the main circuit by means of the wire c^1. H. is a commutator of ordinary construction. When the electro-motive force between the brushes *a.* and *c.* is to the electro-motive force between the brushes *c.* and *b.* as the resistance of the circuit *a.* M. c^1. *c.* A. to the resistance of the circuit *b.* B. *c.* c^1. D. the potentials of the points *x* and *y* will be equal and no current will pass over the auxiliary brush *c.* but if said brush occupies a different position relatively to the main brushes, the electric condition is disturbed and current will flow either from *y* to *x.* or from *x* to *y.* according to the relative position of the brushes.

In the first case the current through the field helices will be partly neutralized and the magnetism of the field magnets diminished; in the second case the current will be increased and the magnets will gain strength. By combining with the brushes *a. b. c.* any automatic regulating mechanism, the current developed can be regulated automatically in proportion to the demands in the working circuit. In practice it is sufficient to move only the auxiliary brush as shown in fig. 4, as the regulator is very sensitive to the slightest changes, but the relative position of the auxiliary brush to the main brushes may be varied by moving the main brushes or both main and auxiliary brushes may be moved as illustrated in fig. 5.

In the latter two cases it will be understood the motion of the main brushes relatively to the neutral line of the machine, causes variations in the strength of the current independently of their relative position to the auxiliary brush.

In all cases the adjustment may be such that when the machine is running with the ordinary load, no current flows over the auxiliary brush.

The field helices may be connected as shown in fig. 7. or a part of the field helices may be in the outgoing and the other part in the return circuit and two auxiliary brushes may be employed as shown in figs. 9. and 10. Instead of shunting the whole of the field helices a portion only of such helices may be shunted as shown in figs. 8. and 10.

The arrangement shown in fig. 10. is advantageous as it diminishes the sparking upon the commutator, the main circuit being closed through the auxiliary brushes at the moment of the break of of the circuit at the main brushes.

The field helices may be wound in the same direction or a part may be wound in opposite directions.

The connection between the helices and the auxiliary brush or brushes may be made by a wire of small resistance, or a resistance may be interposed (R fig. 11.) between the point *x*. and the auxiliary brush or brushes to divide the sensitiveness when the brushes are adjusted.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed I declare that what I claim is

First. The combination with the commutator having two or more main brushes, and an auxiliary brush, of the field helices having their ends connected to the main brushes and a branch or shunt connection from an intermediate point of the field helices to the auxiliary brush and means for varying the relative position upon the commutator of the respective brushes, substantially as set forth.

Second. The combination with the commutator and main brushes and one or more auxiliary brushes, of the field helices in the main circuits and one or more shunt connections from the field helices to the auxiliary brushes, the relative positions upon the commutator of the respective brushes being adjustable for the purposes set forth.

BREWER & SON,
For the Applicant.

LONDON : Printed by DARLING AND SON.
For Her Majesty's Stationery Office.

1887.

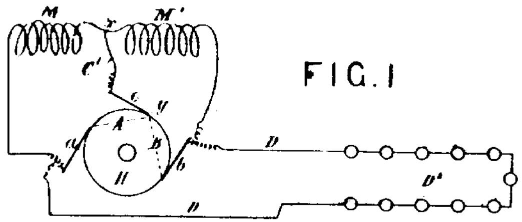

FIG. 1

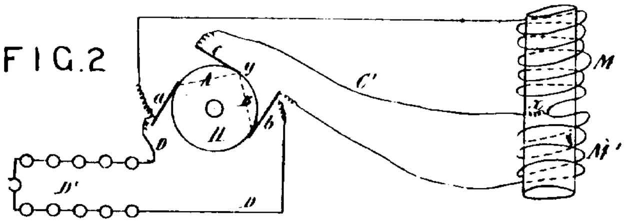

FIG. 2

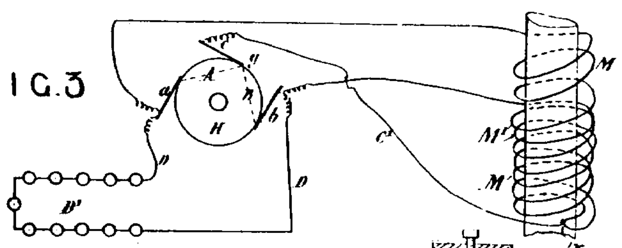

FIG. 3

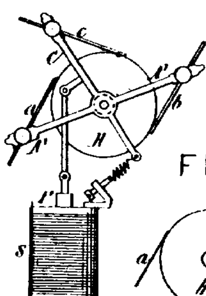

FIG. 4

FIG. 6

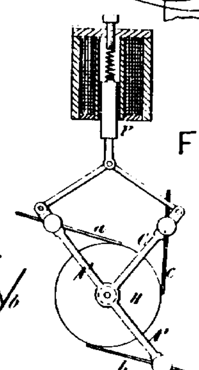

FIG. 5

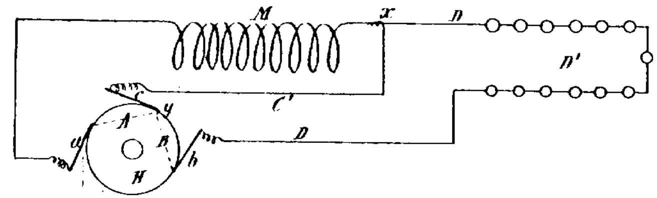

FIG. 7

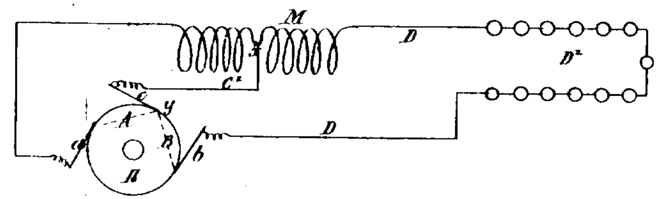

FIG. 8

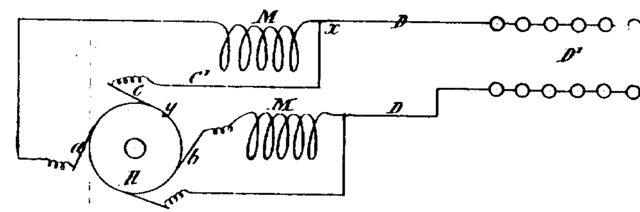

FIG. 9

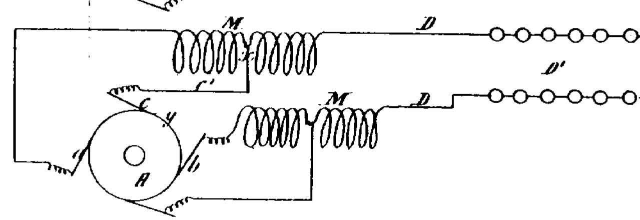

FIG. 10

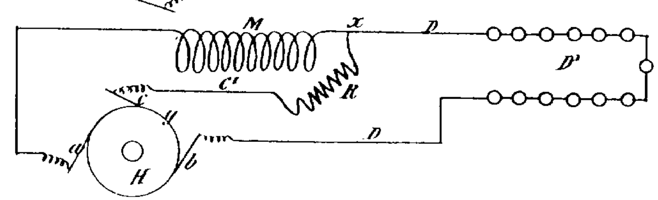

FIG. 11

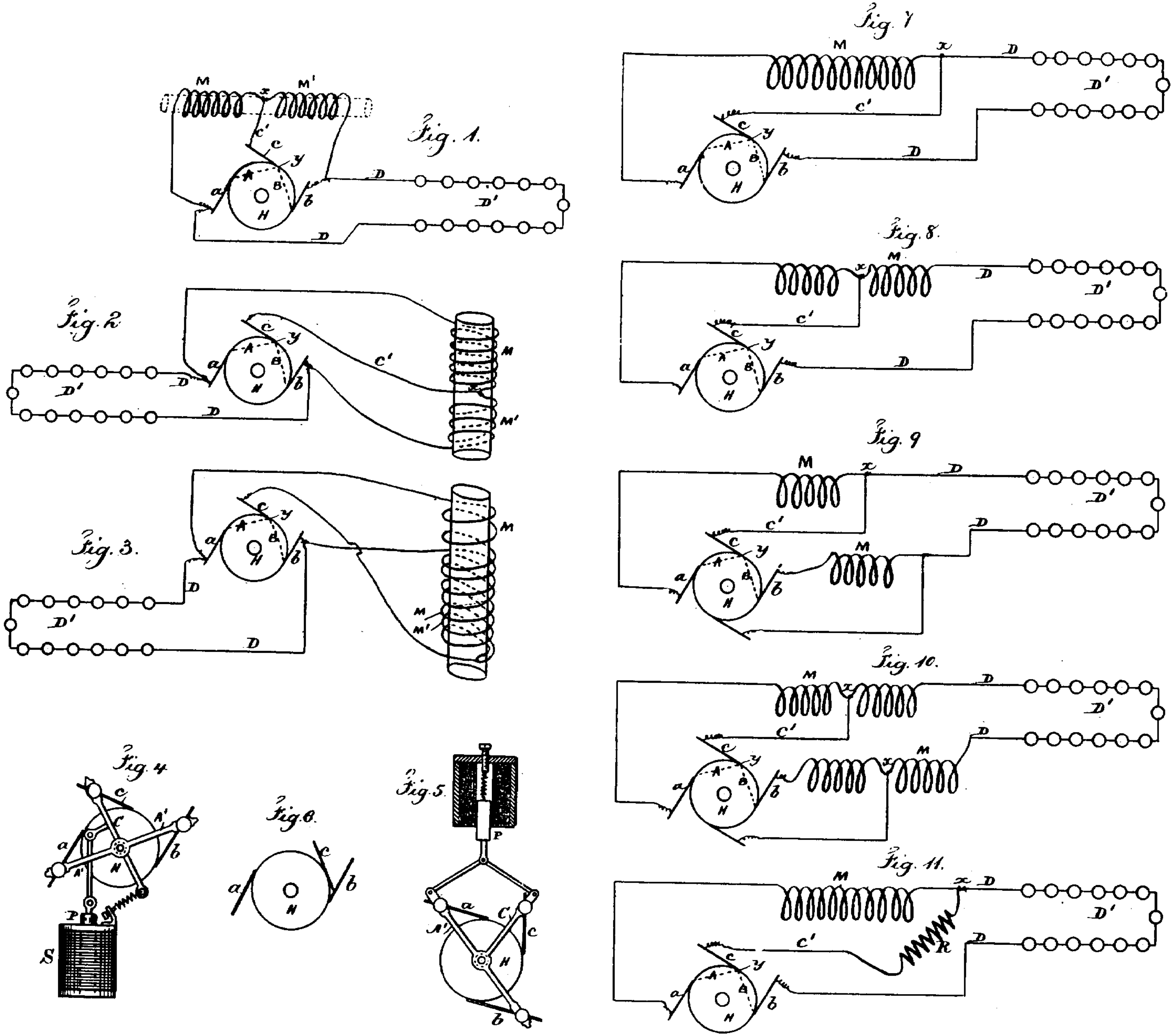
Fig. 1.
Fig. 2
Fig. 3.
Fig. 4
Fig. 5.
Fig. 6.
Fig. 7
Fig. 8.
Fig. 9
Fig. 10.
Fig. 11.
M
M'
x
c
c'
y
A
A'
B
C
H
a
b
D
D'
P
S
R

Date of Application, 1st May, 1888
Specification Accepted, 1st June, 1888

A.D. 1888, 1st MAY. N° 6481.

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of the City and State of New York, United States of America, Electrician.]

Improvements relating to the Electrical Transmission of Power and to Apparatus therefor.

I, HENRY HARRIS LAKE, of the firm of Haseltine, Lake & Co., Patent Agents Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The practical solution of the problem of the electrical conversion and transmission of mechanical energy involves certain requirements which the apparatus and systems heretofore employed have not been capable of fulfilling.

Such a solution primarily demands a uniformity of speed in the motor, irrespective of its load within its normal working limits. On the other hand, it is necessary to attain a greater economy of conversion than has heretofore existed, to construct cheaper, more reliable and simple apparatus, and such that all danger and disadvantages from the use of currents of high tension, which are necessary to an economical transmission, may be avoided.

This invention comprises a new method and apparatus for effecting the transmission of power by electrical agency whereby many of the present objections are overcome and great economy and efficiency secured.

In the practice of this invention a motor is employed in which there are two or more independent energizing circuits through which are passed, in the manner hereinafter described, alternating currents, which effect a progressive shifting of the magnetism or of the "lines of force" which, in accordance with well known theories, produces the action of the motor.

It is obvious that a proper progressive shifting or movement of the lines of force may be utilized to set up a movement or rotation of either element of the motor, the armature of the field magnet, and that if the currents directed through the several circuits of the motor are in the proper direction no commutator for the motor will be required. So, to avoid all the usual commutating appliances in the system, the motor circuits are connected directly with those of a suitable alternating current generator. The practical results of such a system, its economical advantages, and the mode of its construction and operation will be described more in detail by reference to the accompanying drawings and diagrams.

Figures 1 to 8 and 1ª to 8ª, inclusive, are diagrams illustrating the principle of the action of this invention. The remaining Figures are views of the apparatus in various forms by means of which the invention may be carried into effect and which will be described in their order.

Referring first to Figure 9, which is a diagramatic representation of a motor, a generator and connecting circuits in accordance with the invention, M is the motor and G the generator for driving it. The motor comprises a ring or annulus R, preferably built up of thin insulated iron rings or annular plates, so as to be as susceptible as possible to variations in its magnetic condition.

This ring is surrounded by four coils of insulated wire, symmetrically placed, and designated by C C C^1 C^1. The diametrically opposite coils are connected up so as co-operate in pairs in producing free poles on diametrically opposite parts of the ring. The four free ends thus left are connected to terminals T T T^1 T^1 as indicated.

Near the ring, and preferably inside of it, there is mounted on an axis or shaft a magnetic disk D generally circular is shape, but having two segments cut away as shown. This disk should turn freely within the ring R.

The generator G is of an ordinary type, that shown in the present instance having field magnets N S and a cylindrical armature core A, wound with the two coils B B^1. The free ends of each coil are carried through the shaft a^1 and connected respectively, to insulated contact rings b b b^1 b^1. Any convenient form of collector or brush bears on each ring and forms a terminal by which the current to and from the ring is conveyed. These terminals are connected to the terminals of the motor by the wires L and L^1 in the manner indicated, whereby two complete circuits are formed, one including, say, the coils B of the generator and C^1 C^1 of the motor, and the other the remaining coils B^1 and C C of the generator and the motor.

It remains now to explain the mode of operation of this system, and for this purpose reference is made to the diagrams Figures 1 to 8 and 1ª to 8ª for an illustration of the various phases through which the coils of the generator pass when in operation, and the corresponding and resultant magnetic changes produced in the motor.

The revolution of the armature of the generator between the field magnets N S obviously produces in the coils B B^1 alternating currents the intensity and direction of which depend upon well known laws. In the position of the coils, indicated in Figure 1, the current in the coil B is practically *nil*, whereas the coil B^1 at the same time is developing its maximum current, and by the means indicated in the description of Figure 9 the circuit including this coil may also include say, the coils C C of the motor, Figure 1ª. The result, with the proper connections, would be the magnetization of the ring R, the poles being on the line N S.

The same order of connections being observed between the coil B and the coil C^1 C^1, the latter, when traversed by a current, tend to fix the poles at right angles to the line N S of Figure 1ª. It results therefore, that when the generator coils have made one-eighth of a revolution, reaching the position shown in Figure 2, both pairs of coils C and C^1 will be traversed by currents which act in opposition in so far as the location of the poles is concerned. The position of the poles will therefore be determined by the resultant effect of the magnetizing forces of the coils, that is to say, it will advance along the ring to a position corresponding to one-eighth of the revolution of the armature of the generator.

In Figure 3 the armature of the generator has progressed to one-fourth of a revolution. At the point indicated the current in the coil B is maximum while in B^1 it is *nil*, the latter coil being in its neutral position. The poles of the ring R in Figure 3ª will in consequence, be shifted to a position ninety degrees from that at the start as shown. The conditions existing at each successive eighth of one revolution are in like manner shown in the remaining Figures. A short reference to these Figures will suffice to an understanding of their significance. Figures 4 and 4^a illustrate the conditions which exist when the generator armature has completed three-eighths of a revolution. Here both coils are generating current, but the coil B^1 having now entered the opposite field is generating a current in the opposite direction, having the opposite magnetizing effect. Hence, the resultant poles will be on the line N S as shown.

In Figure 5 and 5^a one half of one revolution has been completed with a corresponding movement of the polar line of the motor. In this phase coil B is in its neutral position while coil B^1 is generating its maximum current; the current being in the same direction as in Figure 4.

In Figure 6 the armature has completed five-eighths of a revolution. In this position coil B^1 develops a less powerful current, but in the same direction as before. The coil B on the other hand, having entered a field of opposite polarity, generates a current of opposite direction. The resultant poles will therefore be on the line N S Figure 6^a, or in other words, the poles of the ring will be shifted along five-eighths of its periphery.

Figures 7 and 7^a in the same manner illustrate the phases of the generator and ring at three quarters of a revolution, and Figures 8 and 8^a those at seven-eighths of a revolution of the generator armature. These Figures will be readily understood from the foregoing.

When a complete revolution is accomplished, the conditions existing at the start are reestablished and the same action is repeated for the next and all subsequent revolutions, and in general, it will now be seen that every revolution of the armature of the generator produces a corresponding shifting of the poles or lines of force around the ring.

This effect is utilized to produce the rotation of a body or armature in a variety of ways. For example, applying the principle above described to the apparatus shown in Figure 9; the disk D owing to its tendency to assume that position in which it embraces the greatest possible number of magnetic lines, is set in rotation following the motion of the lines or the points of greatest attraction.

The disk D in Figure 9, is shown as cut away on opposite sides, but this will not be found essential to its operation; as a circular disk, as indicated by dotted lines, would also be maintained in rotation. This phenomenon is probably attributable to a certain inertia or resistance inherent in the metal to the rapid shifting of the lines of force through the same, which results in a continuous tangential pull upon the disk that causes its rotation. This seems to be confirmed by the fact that a circular disk of steel is more effectively rotated than one of soft iron, for the reason that the former is assumed to possess a greater resistance to the shifting of the magnetic lines.

In illustration of other forms of apparatus by means of which this invention may be carried out reference is now made to the remaining figures of the drawings.

Figure 10 is a view in elevation and part vertical section of a motor. Figure 12 is a top view of the same with the field in section and exhibiting a diagram of the connections. Figure 11 is an end or side view of the generator with the fields in section. This form of motor may be used in place of that described.

D is a cylindrical or drum armature core, which for obvious reasons should be split up as far as practicable to prevent the circulation within it of currents of induction. The core is wound longitudinally with two coils E E^1, the ends of which are respectively connected to insulated contact rings d d d^1 d^1 carried by the shaft a upon which the armature is mounted.

The armature is arranged to revolve within an iron shell R which constitutes the field magnet or other element of the motor. This shell is preferably formed with a slot or opening r, but it may be continuous as shown by the dotted lines, and in this event it is perferably made of steel. It is also desirable that this shell should be divided up similarly to the armature and for similar reasons.

The generator for driving this motor may be such as that shown in Figure 11. This represents an annular or ring armature A surrounded by four coils F F F^1 F^1 of which, those diametrically opposite are connected in series so that four free ends are left which are connected to the insulated contact rings b b b^1 b^1. The ring is mounted on a shaft a^1 between the poles N S.

The contact rings of each pair of generator coils are connected to those of the motor respectively by means of contact brushes and the two pairs of conductors L L L^1 L^1, as indicated diagramatically in Figure 12.

It is obvious from a consideration of the preceding Figures that the rotation of the generator ring produces currents in the coils F F^1 which, being transmitted to the motor coils, impart to the armature core of the motor, magnetic poles which are constantly shifted around the core. This effect sets up a rotation of the motor armature owing to the attractive force between the shell R and the poles of the armature, but inasmuch as the coils in this case move relatively to the shell or field magnets the movement of the coils is in the opposite direction to the progressive movement of poles.

Other arrangements of the coils of both generator and motor are possible and a greater number of circuits may be used as will be seen in the two succeeding Figures.

Figure 13 is a diagramatic illustration of a motor and a generator, connected and constructed in accordance with the invention. Figure 14 is an end view of the generator with its field magnets in section.

The field of the motor M is produced by six magnetic poles G^1 G^1 secured to or projecting from a ring or frame H. These magnets or poles are wound with insulated coils, those diametrically opposite to each other being connected in pairs so as to produce opposite poles in each pair. This leaves six free ends which are connected to the terminals.

The armature which is mounted to rotate between the poles is a cylinder or disk D of wrought iron, on the shaft a. Two segments of the disk are cut away as shown.

The generator for this motor has, in this instance, an armature A wound with three coils K K^1 K^{11} at 60 degrees apart. The ends of these coils are connected respectively to insulated contact rings e e e^1 e^1 e^{11} e^{11}. These rings are connected to those of the motor in proper order by means of collecting brushes and six wires forming the independent circuits. The variations in the strength and direction of the currents transmitted through these circuits and traversing the coils of the motor produce a steadily progressive shifting of the resultant attractive forces exerted by the poles G^1 upon the armature D and consequently keep the armature in rapid rotation. The special advantage of this disposition is in obtaining a more concentrated and powerful field. The application of this principle to systems involving multiple circuits generally will be understood from this apparatus.

Referring now to Figures 15 and 16; Figure 15 is a diagramatic representation of a modified disposition of the invention. Figure 16 is a horizontal cross-section of the motor.

In this case a disk D, of magnetic metal, preferably cut away at opposite edges as shown in dotted lines in the Figure, is mounted so as to turn freely inside two stationary coils N^1 N^{11} placed at right angles to one another. The coils are preferably wound on a frame O of insulating material and their ends are connected to the fixed terminals T T T^1 T^1.

The generator G is a representative of that class of alternating current machines in which a stationary induced current is employed. That shown consists of a revolving permanent or electro-magnet A and four independent stationary magnets P P^1 wound with coils. The diametrically opposite coils being connected in series and having their ends secured to the terminals t t t^1 t^1. From these terminals the currents are led to the terminals of the motor, as shown in the drawing.

The mode of operation is substantially the same as in the previous cases, the currents traversing the coils of the motor having the effect to turn the disk D. This mode of carrying out the invention has the advantage of dispensing with the sliding contacts in the system.

In the forms of motor above described, only one of the elements, the armature or the field magnet is provided with energizing coils. It remains then to show how both elements may be wound with coils. Reference is therefore had to Figures 17 and 18.

Figure 17 is an end view of such a motor with the diagram of connections. Figure 18 is a view of the generator with the field magnets in section. In Figure 17 the field magnet of the motor consists of a ring R, preferably of thin insulated iron sheets or bands with eight pole pieces G^1 and corresponding recesses in which four pairs of coils V are wound. The diametrically opposite pairs of coils are connected in series and the free ends connected to four terminals W. The rule to be followed in connection being the same as hereinbefore explained.

An armature D with two coils E E^1 at right angles to each other, is mounted to rotate inside of the field magnet R. The ends of the armature coils are connected to two pairs of contact rings $d\ d\ d^1\ d^1$.

The generator for this motor may be of any suitable kind to produce currents of the desired character. In the present instance it consists of a field magnet N S and an armature A with two coils at right angles, the ends of which are connected to four contact rings $b\ b\ b^1\ b^1$ carried by its shaft.

The circuit connections are established between the rings on the generator shaft and those on the motor shaft by collecting brushes and wires as previously explained. In order to properly energize the field magnet of the motor however, the connections are so made with the armature coils by wires leading thereto, that while the points of greatest attraction or greatest density of magnetic lines of force upon the armature are shifted in one direction, those upon the field magnet are made to progress in an opposite direction. In other respects the operation is identically the same as in the other cases described. This arrangement results in an increased speed of rotation.

In Figure 17, for example, the terminals of each set of field coils are connected with the wires to the armature coils in such way that the field coils will maintain opposite poles in advance of the poles of the armature.

In the drawings the field coils are in shunts to the armature, but they may be in series or in independent circuits.

It is obvious that the same principle may be applied to the various typical forms of motor hereinbefore described.

Figure 19 is a diagram similar to figure 9, illustrating a modification in the motor. In this figure the various parts are the same as in figure 9, except that the armature core of the motor is wound with two coils at right angles to each other, the core being a cylinder or disk. The two coils form independent closed circuits. This arrangement of closed induced circuits will be found to give very efficient results.

When a motor thus constructed is not loaded, but running free, the rotation of the armature is practically synchronous with the rotation of the poles in the field, and under these circumstances very little current is perceptible in the coils C C^1, but if a load is added the speed tends to diminish and the currents in the coil are augmented so that the rotary effect is increased proportionately.

This principle of construction is obviously capable of many modified applications, most of which follow as a matter of course from the constructions described; for instance, the armature or induced coils or those in which the currents are set up by induction, may be held stationary and the alternating currents from the generator conducted through the rotating inducing or field coils by means of suitable sliding contacts. It is also apparent that the induced coils may be movable and the magnetic parts of the motor stationary.

An advantage and a characteristic feature of motors constructed and operated in accordance with this plan, is their capability of almost instantaneous reversal by the reversal of one of the energizing currents from the generator.

This will be understood from a consideration of the working conditions. Assuming the armature to be rotating in a certain direction following the movement of the shifting poles, then let the direction of the shifting be reversed which may be done by reversing the connections of one of the two energizing circuits. If it be borne in mind that in a dynamo-electric machine the energy developed is very nearly proportionate to the cube of the speed it is evident that at such moment an extraordinary power is brought to play in reversing the motor. In addition to this the resistance of the motor is very greatly reduced at the moment of reversal so that a much greater amount of current passes through the energizing circuits.

The phenomenon alluded to, *viz.*: the variation of the resistance of the motor, apparently like that in ordinary motors, is probably attributable to the variation in the amount of self-induction in the primary or energizing circuit.

In lieu of the field magnets for the motors shown in the drawings soft iron field magnets excited by a continuous current may be used.

This plan is a very advantageous one, but it is characteristic of a motor so operated that if the field magnet be strongly energized by its coils and the circuits through the armature coils closed, assuming the generator to be running at a certain speed, the motor will not start but if the field be but slightly energized or in general in such condition that the magnetic influence of the armature preponderates in determining its magnetic condition, the motor will start and, with sufficient current, will reach its normal or maximum speed. For this reason it is desirable to keep, at the start and until the motor has attained its normal speed or nearly so, the field circuit open, or to permit but little current to pass through it.

Another characteristic of this form of motor is, that its direction of rotation is not reversed by reversing the direction of the current through its field coils, for the direction of rotation depends, not upon the polarity of the field, but upon the direction in which the poles of the armature are shifted. To reverse the motor the connections of either of the energizing circuits must be reversed.

It will be found if the fields of both the generator and motor be strongly energized that starting the generator starts the motor, and that the speed of the motor is increased in synchronism with the generator.

Motors constructed and operated upon this principle maintain almost absolutely the same speed for all loads within their normal working limits, and in practice it will be observed that if the motor is suddenly overloaded to such an extent as to check its speed, the speed of the generator, if its motive power be not too great is diminished synchronously with that of the motor. These qualities render this particular form of motor very useful under certain conditions.

With this description of the nature of the invention and of some of the various ways in which it is carried into effect, attention is called to certain characteristics which the applications of the invention possess, and the advantages which it offers.

In this motor, considering for convenience, that represented in Figure 9, it will be observed that since the disk D has a tendency to follow continuously the points of greatest attraction, and since these points are shifted around the ring once for each revolution of the armature of the generator, it follows that the movements of the disk D will be synchronous with that of the armature A. This feature will be found to exist in all other forms in which one revolution of the armature of the generator produces a shifting of the poles of the motor through three hundred and sixty degrees.

In the particular modification shown in Figure 15 or in others constructed on a similar plan, the number of alternating impulses resulting from one revolution of the generator armature is double as compared with the preceding cases, and the polarities in the motor are shifted around twice by one revolution of the generator armature. The speed of the motor will, therefore, be twice that of the generator.

The same result is evidently obtained by such a disposition as that shown in figure 17 where the poles of both elements are shifted in opposite directions.

Again, considering the apparatus illustrated by figure 9, as typical of the invention, it is obvious that since the attractive effect upon the disk D is greatest when the disk is in its proper relative position to the poles developed in the ring R, that is to say, when its ends or poles immediately follow those of the ring, the speed of the motor for all loads within the normal working limits of the motor will be practically constant.

It is clearly apparent that the speed can never exceed the arbitrary limit as determined by the generator, and also that within certain limits, at least, the speed of the motor will be independent of the strength of the current.

It will now be more readily seen from the above description how far the requirements of a practical system of electrical transmission of power are realized by this invention. It secures:

First, a uniform speed under all loads within the normal working limits of the motor without the use of any auxiliary regulator.

Second, synchronism between the motor and generator.

Third, greater efficiency by the more direct application of the current, no commutating devices being required on either the motor or generator.

Fourth, cheapness and simplicity of mechanical construction.

Fifth, the capability of easy management and control.

Sixth, diminution of danger from injury to persons and apparatus.

These motors may be run in series multiple arc or multiple series under conditions well understood by those skilled in the art.

The means or devices for carrying out the principle of this invention may be varied to a far greater extent than has been indicated herein, but the invention includes in general, motors containing two or more independent circuits through which the operating currents are directed in the manner described. By "independent" it is not implied that the circuits are necessarily isolated from one another for in some instances there might be electrical connections between them to regulate or modify the action of the motor without necessarily producing a new or different action.

It is not new to produce the rotation of a motor by intermittently shifting the poles of one of its elements. This has been done by passing through independent energizing coils on one of the elements the current from a battery or other source of direct or continuous currents, reversing such currents by suitable mechanical appliances so that they are directed through the coils in alternately opposite directions. In such cases however, the potential of the energizing current remains the same, their direction only being changed. According to the present invention, on the other hand, true alternating currents are employed and the invention consists in the mode or method of an apparatus for utilizing such currents.

The difference between the two plans and the advantages of this one are obvious. By producing an alternating current each impulse of which involves a rise and fall of potential, the exact conditions of the generator are reproduced in the motor, and by such currents and the consequent productions of resultant poles, the progression of the poles will be continuous and not intermittent. In addition to this, the practical difficulty of interrupting or reversing a current of any considerable strength is such that none of the devices at present known could be made to economically or practically effect the transmission of power by reversing, in the manner described, a continuous or direct current.

In so far, then, as the plan of acting upon one element of the motor is concerned, my invention involves the use of an alternating as distinguished from a reversed current, or a current which while continuous and direct is shifted from coil to coil by any form of commutator, reverser or interruptor. With regard to that part of the invention which consists in acting upon both elements of the motor simultaneously, the use of either alternating or reversed currents is within the scope of the invention, although the use of reversed currents is not regarded as of much practical importance.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed as communicated to me by my foreign correspondent I declare that what I claim is:—

1. The method herein described of electrically transmitting power which consists in producing a continuously progressive movement of the polarities of either or both elements (the armature or field magnet or magnets) of a motor by developing alternating currents in independent circuits including the magnetizing coils of either or both elements, as herein set forth.

2. The combination with a motor containing separate or independent circuits on the armature or field or both, of an alternating current generator containing induced circuits connected independently to corresponding circuits in the motor, whereby a rotation of the generator produces a progressive shifting of the poles of the motor, as herein described.

3. In a system for the electrical transmission of power, the combination of a motor provided with two or more independent magnetizing coils corresponding to the motor coils and circuits connecting directly the motor and generator coils in such order that the currents developed by the generator will be passed through the corresponding motor coils and thereby produce a progressive shifting of the poles of the motor, as herein set forth.

4. The combination with the motor having an annular or ring shaped field and a cylindrical or equivalent armature, and independent coils on the field or armature or both, of an alternating current generator having correspondingly independent coils and circuits including the generator coils and corresponding motor coils in such manner that the rotation of the generator causes a progressive shifting of the poles of the motor in the manner set forth.

5. In a system for the electrical transmission of power, the combination of the following instrumentalities, to wit: A motor composed of a disk or its equivalent, mounted within a ring or annular field which is provided with magnetizing coils connected in diametrically opposite pairs or groups to independent terminals, a generator having induced coils or groups of coils equal in number to the pairs or groups of motor coils and circuits connecting the terminals of said coils to the terminals of the motor respectively and in such order that the rotation of the generator and the consequent production of alternating currents in the respective circuits produces a progressive movement of the polarities of the motor, as hereinbefore described.

6. The method herein described of operating electro-magnetic motors which consists in producing a progressive shifting of the poles of its armature by an alternating current and energizing its field magnets by a continuous current as set forth.

7. The combination with a motor containing independent inducing or energizing circuits and closed induced circuits, of an alternating current generator having induced or generating circuits corresponding to and connected with the energizing circuits of the motor as set forth.

8. An electro-magnetic motor having its field magnets wound with independent coils and its armature with independent closed coils in combination with a source of alternating currents connected to the field coils and capable of progressively shifting the poles of the field magnet, as set forth.

Dated this 1st day of May 1888.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, W.C.,
Agents for the Applicant.

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1888.

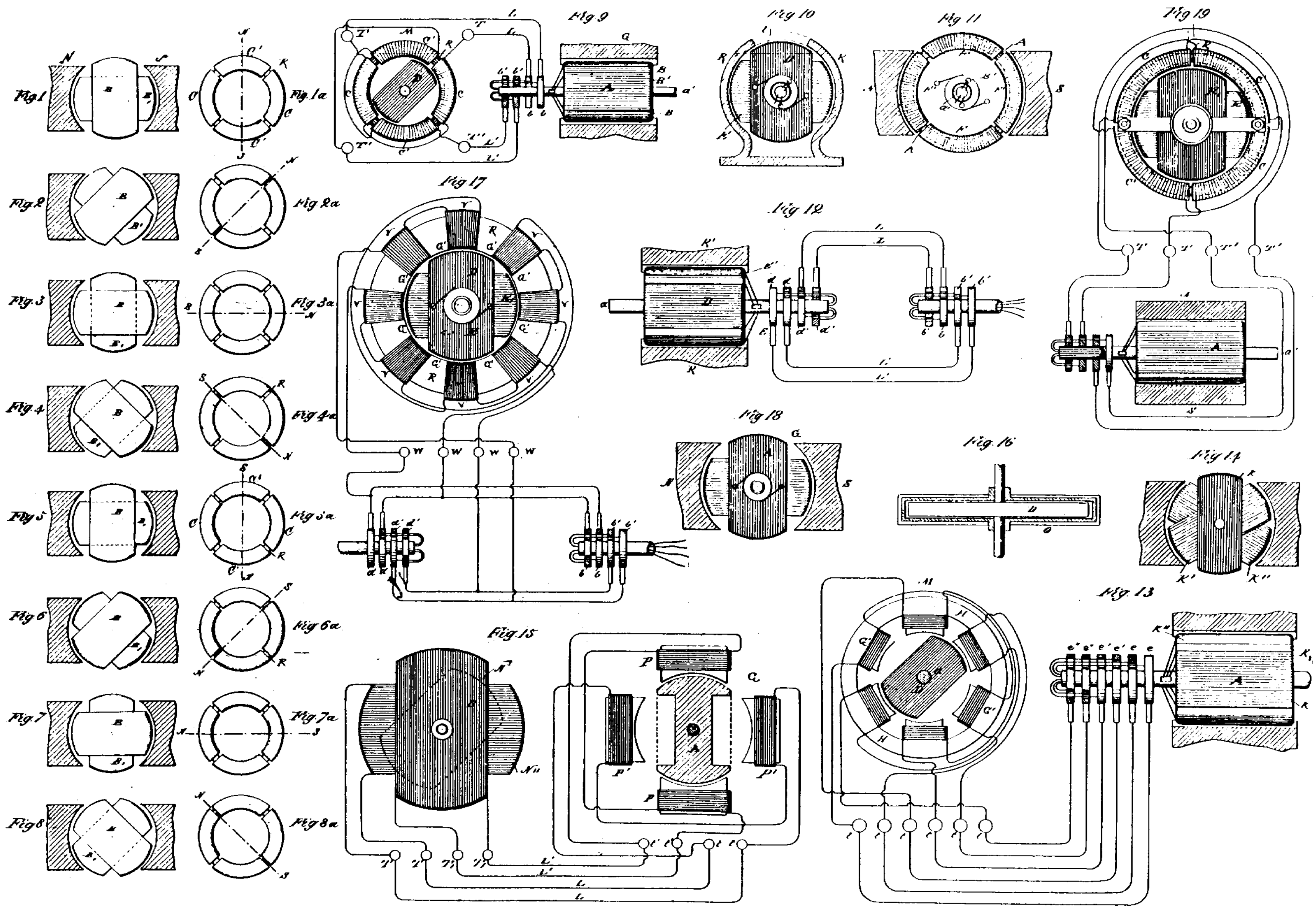
Fig 1
Fig 1a
Fig 2
Fig 2a
Fig 3
Fig 3a
Fig 4
Fig 4a
Fig 5
Fig 5a
Fig 6
Fig 6a
Fig 7
Fig 7a
Fig 8
Fig 8a
Fig 9
Fig 10
Fig 11
Fig 12
Fig 13
Fig 14
Fig 15
Fig 16
Fig 17
Fig 18
Fig 19

Date of Application, 1st May, 1888
Specification Accepted, 1st June, 1888

A.D. 1888, 1st *May*. N° 6502.

COMPLETE SPECIFICATION.

[Communicated from abroad by Nikola Tesla, of the City and State of New York, United States of America, Electrician.]

Improvements relating to the Generation and Distribution of Electric Currents and to Apparatus therefor.

I, Henry Harris Lake, of the firm of Haseltine, Lake & Co., Patent Agents, Southampton Buildings in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to those systems of electrical distribution in which a current from a single source of supply in a main or transmitting circuit, is caused to induce, by means of suitable induction coils, a current or currents in an independent working circuit or circuits.

The main objects of the invention are the same as have heretofore been obtained by the use of these systems, *viz.*: To divide the current from a single source whereby a number of lamps, motors or other translating devices may be independently controlled and operated by the same source of current, and in some cases to reduce a current of high potential in the main circuit to one of greater quantity and lower potential in the independent consumption circuit or circuits.

The general character of these devices is now well understood. An alternating current magneto machine is used as the source of supply. The current developed thereby is conducted through a transmission circuit to one or more distant points at which the transformers are located. These consist of induction machines of various kinds; in some cases ordinary forms of induction coil have been used, with one of the coils in the transmitting circuit and the other in a local or consumption circuit, the coils being differently proportioned according to the work to be done in the consumption circuit. That is to say, if the work requires a current of higher potential than that in the transmission circuit the secondary or induced coil is of greater length and resistance than the primary; while on the other hand, if a quantity current of lower potential is wanted the longer coil is made the primary.

In lieu of these devices various forms of electro-dynamic induction machines, including the combined motors and generators have been devised. For instance, a motor is constructed in accordance with well understood principles and on the same armature are wound induced coils which constitute the generator. The motor coils are generally of fine wire and the generator coils of coarser wire so as to produce a current of greater quantity and lower potential than the line current which is of relatively high potential to avoid loss in long transmission. A similar arrangement is to wind coils corresponding to those described on a ring or similar core and by means of a commutator of suitable kind to direct the current through the inducing coils successively so as to maintain a movement of the poles of the core and of the lines of force which set up the currents in the induced coils.

Without enumerating the objections to these systems in detail, it will suffice to say that the theory or the principle of the action or operation of these devices has apparently been so little understood that their proper construction and use has, up to the present time been attended with various difficulties and great expense. Transformers are very liable to be injured and burnt out, and the means resorted to for curing this and other defects have invariably been at the expense of efficiency.

This invention comprises a method of and apparatus for the conversion and distribution of electrical energy which is not subject to the objections above alluded to and which is both efficient and safe. The result is obtained through a conversion by true dynamic induction under highly efficient conditions, and without the use of expensive or complicated apparatus or moving devices, which in use are liable to wear out or require attention.

This method consists in progressively and continuously shifting the line or points of maximum effect in an inductive field across the convolutions of a coil or conductor within the influence of said field and included in or forming part of a secondary or working circuit.

For carrying out this invention a series of inducing coils and corresponding induced coils is provided, which, by preference are wound upon a core closed upon itself. Such a core, for instance, as is used in the Grammetype of dynamo-machine. The two sets of coils are wound upon this core side by side or superposed, or otherwise placed in well-known ways to bring them into the most effective relations to one another and to the core.

The inducing or primary coils wound on the core are divided into pairs or sets, and they are so connected electrically that while the coils of one pair or set co-operate in fixing the magnetic poles of the core at two given diametrically opposite points, the coils of the other pair or set—assuming for the sake of illustration that there are but two—tend to fix the poles at ninety degrees from such points.

With this induction device or converter an alternating current generator is used with coils or sets of coils to correspond with those of the converter and by means of suitable conductors the corresponding coils of the generator and converter are connected up in independent circuits. It results from this that the different electrical phases in the generator are attended by corresponding magnetic changes in the converter or in other words, that as the generator coils revolve, the points of greatest magnetic intensity in the converter will be progressively shifted or whirled around. This principle of operation may be variously modified and applied to the operation of electro-magnetic motors and the various conditions under which it may be so applied will suggest modifications in the present system. The intention herein, therefore, is merely to describe the best and the most convenient manner for carrying out the invention as applied to a system of electrical distribution. It will be understood that the form of both the generator and converter may be very greatly modified.

In illustration of the details of construction which the invention involves, reference is made to the accompanying drawings. The Figure being a diagram of the converter and the generator with their proper electrical connections.

A is a core which is closed upon itself, that is to say, it is of an annular, cylindrical or equivalent form; and as the efficiency of the apparatus is largely increased by the subdivision of this core it is made of thin strips plates or wires of soft iron electrically insulated from one another as far as practicable. Upon this core by any well known method are wound, for example, four coils B B B^1 B^1 which constitute the primary coils and which are composed of long lengths of comparatively fine wire. Over these coils shorter coils of coarser wire C C C^1 C^1 are wound which constitute the induced or secondary coils. The construction of this or any equivalent form of converter may be carried further by enclosing these coils with iron as, for example, by winding over the coils a layer or layers of insulated iron wire.

The device is provided with suitable binding posts to which the ends of the coils are connected. The diametrically opposite coils B B and B^1 B^1 are connected respectively in series and the four terminals are connected to the binding posts. The induced coils are connected together in any desired manner. For example, coils C C may be connected in multiple arc when a quantity current is desired, as for running a group of incandescent lamps D, while C^1 C^1 may be independently connected in series in a circuit including arc lamps or the like.

The generator in this system will be adapted to the converter in the manner illustrated. For example, in the present case it consists of a pair of ordinary permanent or electro-magnets E E, between which a cylindrical armature core is mounted on a shaft F and wound with two coils G G^1. The terminals of these coils are connected respectively to four insulated or collecting rings H H H^1 H^1 and the four line circuit wires L connect the brushes K bearing on these rings to the converter in the order shown.

Noting the results of this combination it will be observed that at a given point of time the coil G is in its neutral position and is generating little or no current, while the other coil G^1 is in a position where it exerts its maximum effect. Assuming coil G to be connected in circuit with coils B B of the converter and coil G^1 with coils B^1 B^1 it is evident that the poles of the ring A at such point of time will be determined by the current in coils B^1 B^1 alone. But as the armature of the generator revolves coil G develops more current and coil G^1 less, until G reaches its maximum and G^1 its neutral position.

The obvious result will be to shift the poles of the ring A through one quarter of its periphery. The movement of the coils of the generator through the next quarter of a turn, during which coil G^1 enters a field of opposite polarity and generates a current of opposite direction, and increasing strength, while coil G is passing from its maximum to its neutral position and generates a current of decreasing strength and same direction as before and causes a further shifting of the poles through the second quarter of the ring. The second half revolution will obviously be a repetition of the same action.

By shifting the poles of the ring A a powerful dynamic inductive effect is exerted upon the coils C C^1.

Besides the currents generated in the secondary coil by dynamo-magnetic induction, other currents will be set up in the same coils in consequence of any variation in the intensity of the poles in the ring A. This should be avoided by maintaining the intensity of the poles constant, to accomplish which care should be taken in designing and proportioning the generator and in distributing the coils on the ring A and balancing their effect. When this is done the currents are produced by dynamo-magnetic induction only, the same result being obtained as though the poles were shifted by a commutator with an infinite number of segments.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed as communicated to me by my foreign correspondent I declare that what I claim is:—

1. The method of electrical conversion and distribution herein described which consists in continuously and progressively shifting the points or lines of maximum effect in an inductive field and inducing thereby currents in the coils or convolutions of a circuit located within the inductive influence of said field, as herein set forth.

2. The method of electrical conversion and distribution herein described which consists in generating in independent circuits producing an inductive field, alternating

currents in such order or manner as to produce by their conjoint effect a progressive shifting of the points of maximum effect of the field and inducing thereby currents in the coils or convolutions of a circuit located within the inductive influence of the field, as set forth.

3. The combination with a core closed upon itself, inducing or primary coils wound thereon and connected up in independent pairs or sets and induced or secondary coils wound upon or near the primary coil, of a generator of alternating currents and independent circuits connecting the primary coils with the corresponding coils of the generator, as herein set forth.

4. The combination with independent electric transmission circuits, of transformers consisting of annular or similar cores wound with primary and secondary coils the opposite primary coils of each transformer being connected to one of the transmission circuits, an alternating current generator with independent induced or armature coils connected with the transmission circuit whereby alternating currents may be directed through the primary coils of the transformers in the order and manner herein described.

Dated this 1st day of May 1888.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, W.C.,
Agents for the Applicant.

LONDON: Printed for Her Majesty's Stationery Office,
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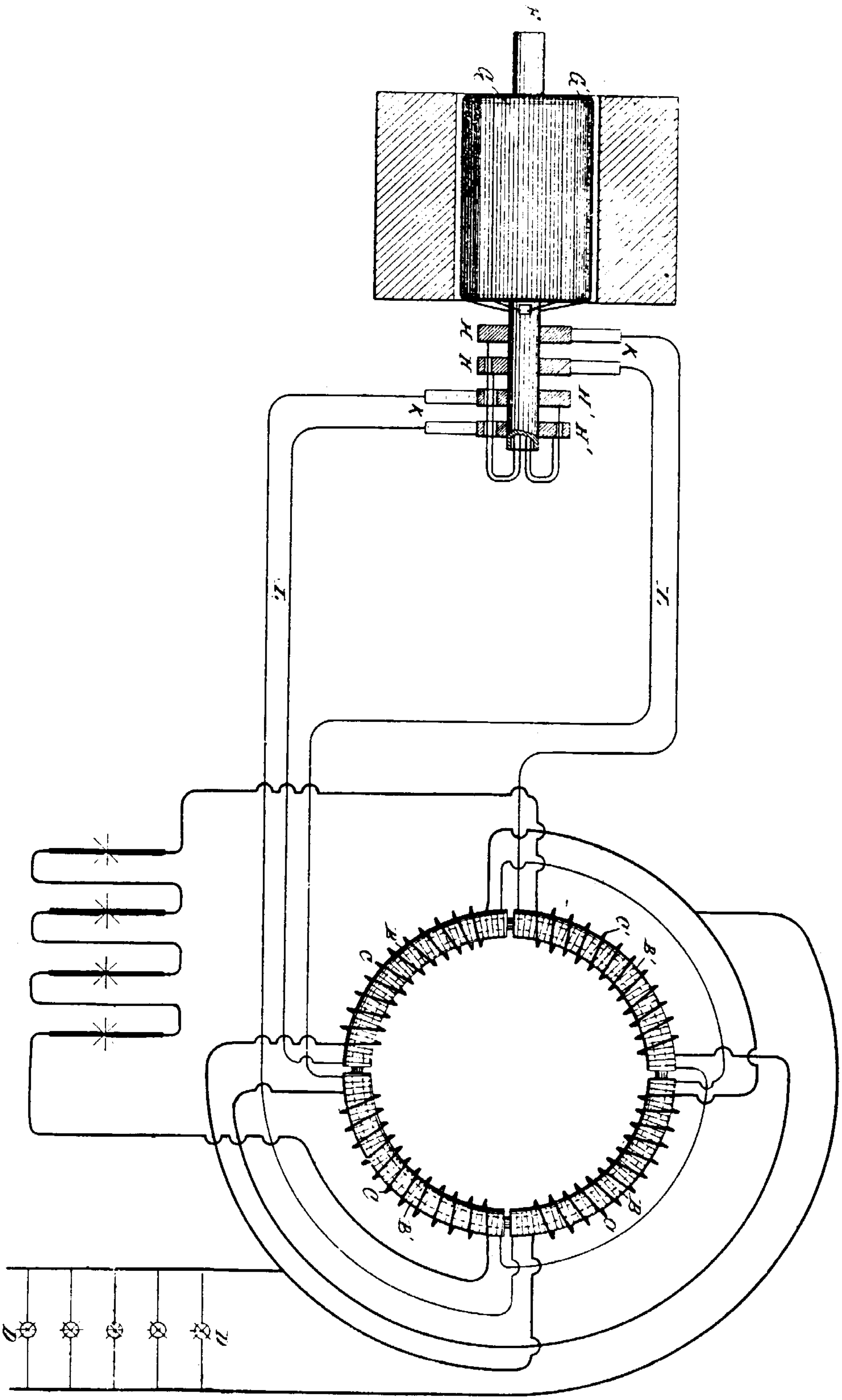
1888.

A.D. 1888. May 1. N° 6502.

LAKE'S Complete Specification.



[Third Edition.]

N° 6527 A.D. 1889

Date of Application, 16th Apr., 1889—Accepted, 18th May, 1889

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of the City and State of New York, United States of America, Electrician.]

Improvements relating to Electro-motors.

I, HENRY HARRIS LAKE, of the firm of Haseltine Lake & Co., Patent Agents, 45, Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

As is well known, certain forms of alternating current machines have the property, when connected in circuit with an alternating current generator, of running as a motor in synchronism therewith. But, while the alternating current will run the motor after it has attained a rate of speed synchronous with that of the generator, it will not start it, hence in all instances heretofore, where these synchronizing motors, as they are termed, have been run, some means have been adopted to bring the motors up to synchronism with the generator, or approximately so, before the alternating current of the generator is applied to drive them. In some instances mechanical appliances have been utilized for this purpose, in others, special and complicated forms of motor have been constructed.

This invention consists in a much more simple method or plan of operating synchronizing motors and one which requires practically no other apparatus than the motor itself. In other words, by a certain change in the circuit connections of the motor, it is converted at will from a double circuit motor, or such as is now known as a Tesla motor and which will start under the action of an alternating current, into a synchronizing motor, or one which will be run by the generator only when it has reached a certain speed of rotation synchronous with that of the generator.

The expression, synchronous with that of the generator, is used herein in its ordinary acceptation, that is to say, a motor is said to synchronize with the generator when it preserves a certain relative speed determined by its number of poles and the number of alternations produced per revolution of the generator. Its actual speed therefore may be faster or slower than that of the generator, but it is said to be synchronous so long as it preserves the same relative speed.

In carrying out this invention a motor is constructed which has a strong tendency to synchronism with the generator. The construction preferred for this is that in which the armature is provided with polar projections. The field magnets are wound with two sets of coils, the terminals of which are connected to a switch mechanism, by means of which the line current may be carried directly through the said coils or indirectly through paths by which its phases are modified.

To start such a motor, the switch is turned on to a set of contacts which includes in one motor circuit a dead resistance, in the other an inductive resistance, and the two circuits being in derivation it is obvious that the difference in phase of the current in such circuits will set up a rotation of the motor.

When the speed of the motor has been brought to the desired rate the switch is shifted to throw the main current directly through the motor circuits and although the currents in both circuits will now be of the same phase, the motor will continue to revolve, becoming a true synchronous motor. To secure greater efficiency, the armature or its polar projections are wound with coils closed on themselves.

There are various modifications and important features of this method or plan but the main principle of the invention will be understood from the foregoing.

The general features of construction and operation which distinguish the present invention are illustrated in the accompanying drawing in which

Figure 1 is a view illustrating the details of the plan above set forth, and

Figures 2 and 3 are modifications of the same.

Referring to Figure 1, let A designate the field magnets of a motor, the polar projections of which are wound with coils B, C, included in independent circuits, and D the armature with polar projections wound with coils E closed upon themselves. The motor in these respects being similar in construction to that described in British Patent dated May 1st 1888, No. 6,481, but having, by reason of the polar projections on the armature core, or other similar and well known features, the properties of a synchronizing motor.

L L^1, represent the conductors of a line from an alternating current generator G.

Near the motor is placed a switch the action of which is that of the one shown in the drawing, which is constructed as follows: F, F^1 are two conducting plates or arms pivoted at their ends and connected by an insulting cross bar H so as to be shifted in parallelism.

In the path of the bars F, F^1, is the contact 2 which forms one terminal of the circuit through coils C, and the contact 4 which is one terminal of the circuit through coils B. The opposite end of the wire of coils C is connected to the wire L or bar F^1 and the corresponding end of coils B is connected to wire L^1 and bar F, hence if the bars be shifted so as to bear on contacts 2 and 4, both sets of coils B, C, will be included in the circuit L, L^1, in multiple arc or derivation.

In the path of the levers F, F^1, are two other contact terminals 1 and 3. The contact 1 is connected to contact 2 through an artificial resistance I and contact 3 with contact 4 through a self induction coil J, so that when the switch levers are shifted on to the points 1 and 3, the circuits of coils B and C will be connected in multiple arc or derivation to the circuit L, L^1, and will include the resistance and self induction coil respectively.

A third position of the switch is that in which the levers F and F^1 are shifted out of contact with both sets of points. In this case the motor is entirely out of circuit.

The purpose and manner of operating the motor by these devices are as follows: The normal position of the switch, the motor being out of circuit, is off the contact points. Assuming the generator to be running and that it is desired to start the motor, the switch is shifted until its levers rest upon points 1 and 3. The two motor circuits are thus connected with the generator circuit, but by reason of the presence of the resistance I in one and the self-induction coil J in the other, the coincidence of the phases of the current is disturbed sufficiently to produce a progression of the poles which starts the motor in rotation. When the speed of the motor has run up to synchronism with the generator or approximately so the switch is shifted over onto to the points 2 and 4, thus cutting out the coils I and J so that the currents in both circuits have the same phase, but the motor now runs as a synchronous motor, which is well known to be a very desirable and efficient means for converting the transmitting power.

It will be understood that when brought up to speed the motor will run with only one of the circuits B or C connected with the main or generator circuit, or the two circuits may be connected in series. This latter plan is preferable when a current having a high number of alternations per unit of time is employed to drive the motor.

In such case the starting of the motor is more difficult and the dead and inductive resistances must take up a considerable proportion of the electro-motive force of the circuits. Generally, the conditions are so adjusted that the electro-motive force used in each of the motor circuits is that which is required to operate the motor when its circuits are in series.

The plan to be followed in this case is illustrated in Figure 2. In this diagram the motor has twelve poles and the armature has polar projections D wound with closed coils E. The switch used is of substantially the same construction as that shown in the previous Figure. There are, however, five contacts, which are designated by the figures 5, 6, 7, 8 and 9. The motor circuits B, C, which include alternate field coils are connected to the terminals in the following order: One end of circuit C is connected to contact 9, and to contact 5 through a dead resistance I. One terminal of circuit B is connected to contact 7 and to contact 6 through a self induction coil J. The opposite terminals of both circuits are connected to contact 8.

One of the levers, as F, of the switch is made with an extension *f* or otherwise so as to cover both contacts 5 and 6 when shifted into the position to start the motor. It will be observed that when in this position and with lever F^1 on contact 8 the current divides between the two circuits B, C, which from their difference in electrical character, produce a progression of the poles that starts the motor in rotation. When the motor has attained the proper speed, the switch is shifted so that the levers cover the contacts 7 and 9, thereby connecting circuits B and C in series. It will be found that by this disposition, the motor is maintained in rotation in synchronism with the generator.

This principle of operation which consists in converting, by a change of connections, or otherwise, a double circuit motor, or one operating by a progressive shifting of the poles, into an ordinary synchronizing motor, may be carried out in many other ways for instance, instead of using the switch shown in the previous figures, a temporary ground circuit between the generator and motor may be used in order to start the motor, in substantially the manner indicated in Figure 3.

Let G in this figure represent an ordinary alternating current generator with say four poles M M^1 and an armature wound with two coils N N^1 at right angles and connected in series. The motor has, for example, four poles wound with coils B C which are connected in series, and an armature with polar projections D wound with closed coils E, E.

From the common joint or union between the two circuits of both the generator and the motor and earth connection is established while the terminals or ends of the said circuits are connected to the line.

Assuming that the motor is a synchronizing motor or one that has the capability of running in synchronism with the generator but not of starting, it may be started by the above described apparatus by closing the ground connection from both generator and motor.

The system thus becomes one with a two circuit generator and motor, the ground forming a common return for the currents in the two circuits L and L^1. When by this arrangement of circuits the motor is brought to speed the ground connection is broken between the motor or generator or both and ground, switches P P^1 being employed for this purpose. The motor then runs as a synchronizing motor.

In the description of those features which constitute the invention, illustrations are omitted of the appliances used in conjunction with the electrical devices of similar systems, such for instance, as driving belts, fixed and loose pulleys for the motor, and the like. But these matters well understood.

This invention though described by reference to specific apparatus is not confined to the use of that shown, but includes generally the method or plan of operating motors by first producing a progressive movement or rotation of their poles or points of maximum effect and then, after the motor has reached a certain speed, alternating its poles, or in other words, by a change in the order or character of the circuit connections, to convert a motor operating on one principle to one operating on another, for the purpose described.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed as communicated to me by my foreign correspondent I declare that what I claim is:—

First. The method of operating an alternating current motor herein described by first progressively shifting or rotating its poles or points of greatest attraction and then, when the motor has attained a given speed, alternating the said poles, as described.

Second. The method of operating an electro-magnetic motor herein described which consists in passing through independent energizing circuits of the motor alternating currents differing in phase and then, when the motor has attained a given speed, alternating currents coinciding in phase, as described.

Third. The method of operating an electro-magnetic motor herein described which consists in starting the motor by passing alternating currents differing in phase through independent energizing circuits, and then, when the motor has attained a given speed, joining the energizing circuits in series and passing an alternating current through the same.

Fourth. The method of operating a synchronizing motor which consists in passing an alternating current through independent energizing circuits of the motor and introducing into such circuits a resistance and self-induction coil whereby a difference of phase between the currents in the circuits will be obtained and then, when the speed of the motor synchronizes with that of the generator, withdrawing the resistance and self-induction coil, as set forth.

Dated this 16th day of April 1889.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London,
Agents for the Applicant.

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[G. 6342—125—1/1902.]

(2nd Edition)

Fig. 1

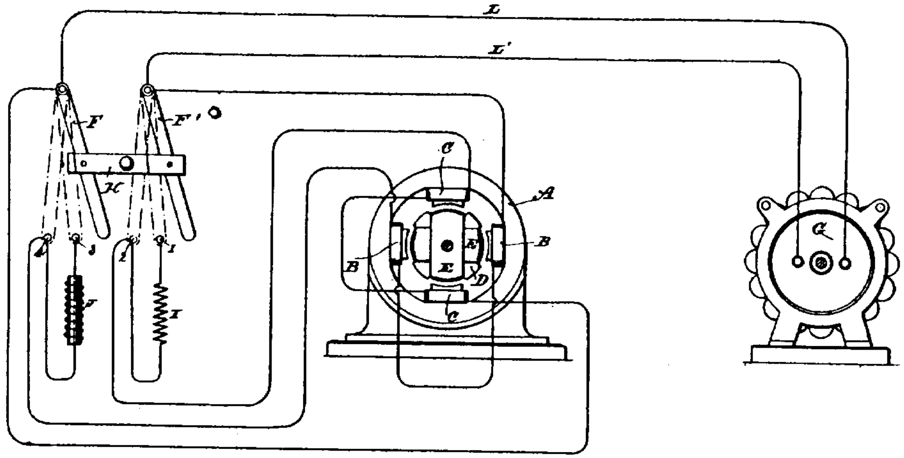


Fig. 2

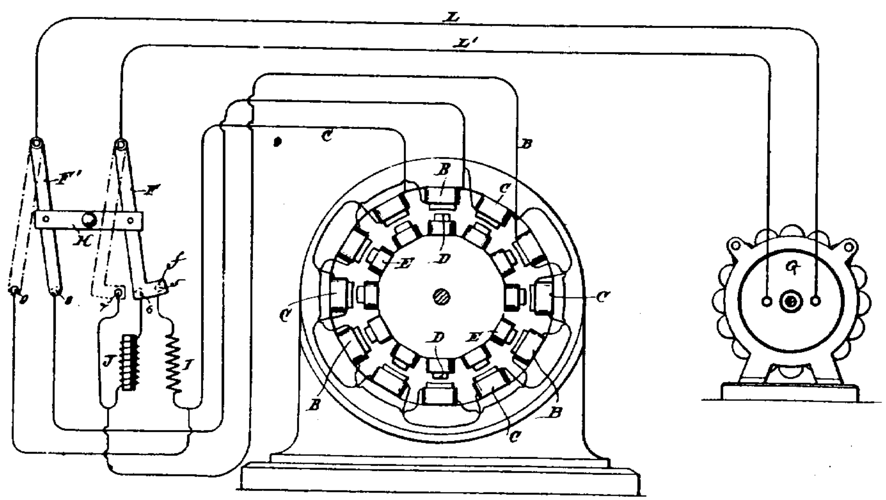
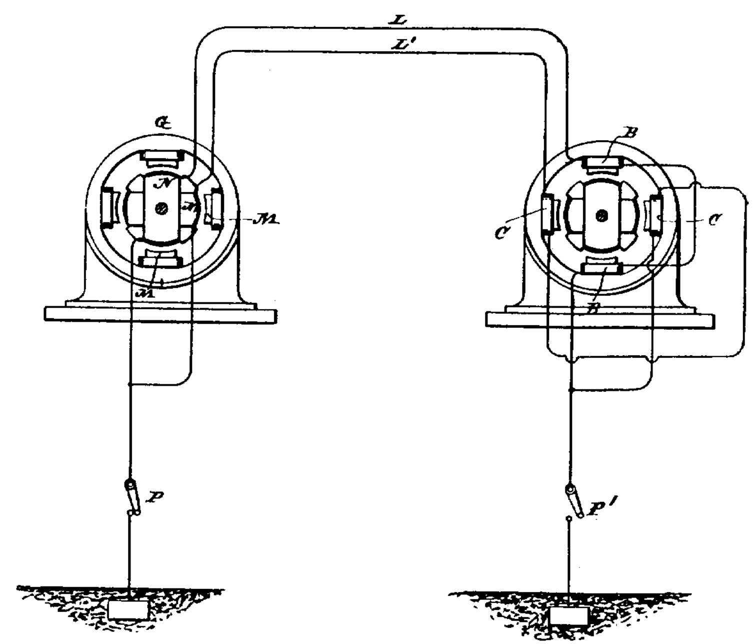


Fig. 3



N° 8200 A.D. 1905

Date of Application, 17th Apr., 1905—Accepted, 17th Apr., 1906

COMPLETE SPECIFICATION.

Communicated by NIKOLA TESLA, of New York, United States of America, Electrician.

"Improvements relating to the Transmission of Electrical Energy".

I, HENRY HARRIS LAKE, of the Firm of Haseltine, Lake & Co., Patent Agents, 7 & 8 Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to the transmission of electrical energy.

It has long since been known that electric currents may be propagated through the earth, and this knowledge has been utilised in many ways in the transmission of signals and the operation of a variety of receiving devices, remote from the source of energy, mainly with the object of dispensing with a return conducting wire.

It is also known that electrical disturbances may be transmitted through portions of the earth by grounding only one of the poles of the source, and this fact I have made use of in systems, which I have devised for the purposes of transmitting through the natural media, intelligible signals or power, and which are now familiar. But all experiments and observations heretofore made have tended to confirm the opinion held by the majority of scientific men, that the earth, owing to its immense extent, although possessing conducting properties, does not behave in the manner of a conductor of limited dimensions with respect to the disturbances produced, but on the contrary, much like a vast reservoir, or ocean which, while it may be locally disturbed by a commotion of some kind, remains unresponsive and quiescent in a large part or as a whole.

Still another fact, now of common knowledge is, that when electrical waves or oscillations are impressed upon such a conducting path as a metallic wire, reflection takes place under certain conditions, from the ends of the wire and, in consequence of the interference of the impressed and reflected oscillations, the phenomenon of "stationary waves", with maxima and minima indefinite, fixed positions, is produced. In any case the existence of these waves indicates, that some of the outgoing waves have reached the boundaries of the conducting path and have been reflected from the same.

Now I have discovered, that notwithstanding its vast dimensions and contrary to all observations heretofore made, the terrestrial globe may, in a large part or as a whole, behave towards disturbances impressed upon it in the same manner as a conductor of limited size, this fact being demonstrated by novel phenomena which I shall hereinafter describe.

In the course of certain investigations which I carried on for the purpose of studying the effects of lightning discharges upon the electrical condition of the earth, I observed that sensitive receiving instruments, arranged so as to be capable of responding to electrical disturbances created by the discharges, at times failed to respond, when they should have done so and, upon inquiring into the causes of this unexpected behaviour, I discovered it to be due to the character of the electrical waves, which were produced in the earth by the lightning discharges and which had nodal regions following at definite distances, the shifting source of the disturbances. From data obtained in a large number of observations of the maxima and minima of these waves, I found their length to vary, approximately from twenty-five to seventy kilometres, and these results and certain theoretical deductions led me to the conclusion, that waves of this kind may be propagated in all directions over the globe, and that they may be of still more widely differing lengths, the extreme limits being imposed by the physical dimensions and properties of the earth.

Recognizing in the existence of these waves an unmistakable evidence that the disturbances created had been conducted from their origin to the most remote portions of the globe and had been thence reflected, I conceived the idea of producing such waves in the earth by artificial means, with the object of utilizing them for many useful purposes, for which they are, or might be found applicable.

This problem was rendered extremely difficult, owing to the immense dimensions of the earth and consequently enormous movement of electricity, or rate at which electrical energy had to be delivered in order to approximate, even in a remote degree, movements or rates which were manifestly attained in the displays of electrical forces in nature, and which seemed at first unrealizable by any human agencies. But by gradual and continuous improvements of a generator of electrical oscillations, which I have described in the Specifications of my United States Patents Nos. 645,576 and 649,621, and in the Specification of my British Patent No. 24,421 of 1897, I finally succeeded in reaching electrical movements, or rates of delivery of electrical energy, not only approximating but, as shown in many comparative tests and measurements, actually surpassing those of lightning discharges, and by means of this apparatus I have found it possible to reproduce, whenever desired, phenomena in the earth the same as, or similar to those due to such discharges.

With the knowledge of the phenomena discovered by me and the means at command for accomplishing these results, I am enabled not only to carry out many operations by the use of known instruments, but also to offer a solution for many important problems, involving the operation or control of remote devices which, for want of this knowledge and in the absence of these means, have heretofore been entirely impossible.

For example, by the use of such a generator of stationary waves and receiving apparatus, properly placed and adjusted in any other locality, however remote, it is practicable to transmit intelligible signals; or to control or actuate at will any or all of such apparatus for many other important and valuable purposes, as for indicating, wherever desired, the correct time of an observatory; or for ascertaining the relative position of a body or distance of the same with reference to a given point; or for determining the course of a moving object such as a vessel at sea, the distance traversed by the same or its speed; or for producing many other useful effects at a distance dependent on the intensity, wave-length, direction or velocity of movement, or other feature or property of disturbances of this character.

I shall typically illustrate the manner of applying my discovery by describing one of the specific uses of the same, namely, the transmission of intelligible signals or messages between distant points, and with this object reference is now made to the accompanying drawing, in which:—

Figure 1 represents diagrammatically the generator which produces stationary waves in the earth,

Figure 2 an apparatus, situated in a remote locality, for recording the effects of these waves, and

Figure 3 the usual arrangement of the circuits of my receiving transformer.

In Figure 1 A designates a primary coil forming part of a transformer and consisting generally of a few turns of a stout cable of inappreciable resistance, the ends of which are connected to the terminals of a source of powerful electrical oscillations, diagrammatically represented by G. This source is usually a condenser charged to a high potential, and discharged, in rapid succession through the primary, as in a type of transformer invented by me and now well known, having been described in my patents on apparatus of this kind, of which it will be sufficient to mention my British Patent No. 20,981 of 1896. But when it is desired to produce stationary waves of great lengths, an alternating dynamo of suitable construction may be used to energize the primary A.

C is a spirally wound secondary coil within the primary, having the end nearer the latter connected to the ground E, and the other to an elevated terminal D. The physical constants of coil C, determining its period of vibration, are so chosen and adjusted, that the secondary system E C D is in the closest possible resonance with the oscillations impressed upon it by the primary A. It is moreover, of the greatest importance, in order to still further enhance the rise of pressure and to increase the electrical movement in the secondary system, that its resistance be as small as practicable and its self-induction as large as possible under the conditions imposed. The ground should be made with great care, with the object of reducing its resistance.

Instead of being directly grounded, as indicated, the coil C may be joined, in series or otherwise, to the primary A, in which case the latter will be connected to the plate E. But be it that none, or a part, or all of the primary or exciting turns are included in the coil C, the total length of the conductor from the ground plate E to the elevated terminal should be equal to one quarter of the wave-length of the electrical disturbance in the system E C D, or else equal to that length multiplied by an odd number. This relation being observed, the terminal D will be made to coincide with the points of maximum pressure in the secondary or excited circuit, and the greatest flow of electricity will take place in the same. In order to magnify the electrical movement in the secondary as much as possible, it is essential that its inductive connection with the primary A should not be very intimate, as in ordinary transformers, but loose, so as to permit free oscillation. That is to say, their mutual induction should be small. The spiral form of coil C secures this advantage, while the turns near the primary A are subjected to a strong inductive action and develop a high initial electromotive force.

These adjustments and relations being carefully completed, and other constructive features indicated rigorously observed, the electrical movement produced in the secondary system by the inductive action of the primary A will be enormously magnified, the increase being directly proportionate to the inductance and frequency, and inversely to the resistance of the secondary system. I have found it practicable to produce in this manner an electrical movement thousands of times greater than the initial, that is, the one impressed upon the secondary by the primary A, and I have thus reached activities or rates of flow of electrical energy in the system E C D, measured, by many tens of thousands of horse-power. Such immense movements of electricity give rise to a variety of novel and striking phenomena, among which are those already described. The powerful electrical oscillations in the system E C D, being communicated to the ground, cause corresponding vibrations to be propagated to distant parts of the globe, whence they are reflected and, by interference with the outgoing vibrations, produce stationary waves, the crests and hollows of which lie in parallel circles, relatively to which the ground plate E may be considered to be the pole. Stated otherwise, the terrestrial conductor is thrown into resonance with the oscillations impressed upon it just like a wire. More than this, a number of facts ascertained by me clearly show, that the movement of electricity through it follows certain laws with nearly mathematical rigor. For the present it will be sufficient to state, that the earth behaves like a perfectly smooth or polished conductor of inappreciable resistance, with capacity and self-induction uniformly distributed along the axis of symmetry of wave propagation and transmitting slow electrical oscillations without sensible distortion and attenuation. Besides the above, three requirements seem to be essential to the establishment of the resonating condition.

1. The earth's diameter passing through the pole should be an odd multiple of the quarter wave-length, that is, of the ratio between the velocity of light and four times the frequency of the currents.

2. It is necessary to employ oscillations, in which the rate of radiation of energy into space in the form of Hertzian or electromagnetic waves is very small. To give an idea I would say, that the frequency should be smaller than twenty thousand per second, though shorter waves might be practicable. The lowest frequency would appear to be six per second, in which case there will be but one node, at or near the ground plate, and, paradoxical as it may seem, the effect will increase with the distance and will be greatest in a region diametrically opposite the transmitter. With oscillations still slower the earth, strictly speaking, will not resonate, but simply act as a capacity, and the variation of potential will be more or less uniform over its entire surface.

3. The most essential requirement is, however, that irrespective of frequency, the wave or wave train should continue for a certain interval of time, which I have estimated to be not less than one twelfth—or probably 0.08484—of a second, and which is taken in passing to, and returning from the region diametrically opposite the pole, over the earth's surface, with a mean velocity of about 471,240 kilometers per second.

The presence of the stationary waves may be detected in many ways. For instance, a circuit may be connected directly, or inductively, to the ground and to an elevated terminal, and tuned to respond more effectively to the oscillations. Another way is to connect a tuned circuit to the ground and to two points lying more or less in a meridian passing through the pole E, or generally stated, to any two points of a different potential.

In Fig. 2 I have shown a device for detecting the presence of the waves, such as I have used in a novel method of magnifying feeble effects, which I have described in my United States Patents Nos. 685,953 and 685,955 and my British Patent No. 11,293 of 1901. It consists of a cylinder C^2 of insulating material which is moved at a uniform rate of speed, by clockwork or other suitable motive power, and is provided with two metal rings B B^1, upon which bear brushes *a* and a^1, connected respectively, to the terminal plates P and P^1. From the rings B and B^1 extend narrow metallic segments S and S^1, which, by the rotation of the cylinder C^2 are brought alternately into contact with double brushes *b* and b^1, carried by, and in contact with, conducting holders *h* and h^1, supported in metallic bearings D and D^1, as shown. The latter are connected to the terminals T and T^1 of a condenser C, and it should be understood that they are capable of angular displacement, as ordinary brush supports. The object of using two brushes, as *b* and b^1, in each of the holders *h* and h^1, is to vary at will the duration of the electric contact of the plates P and P^1, with the terminals T and T^1, to which is connected a receiving circuit including a receiver R, and a device performing the duty of closing the receiving circuit at predetermined intervals of time and discharging the stored energy through the receiver. In the present case this device consists of a cylinder *d* made partly of conducting and partly of insulating material *e* and e^1, respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part *e* is in good electrical connection with the shaft S, and is provided with tapering segments *f f f*, upon which slide a brush *k* supported on a conducting rod *l*, capable of longitudinal adjustment in a metallic support *m*. Another brush *n* is arranged to bear upon the shaft S, and it will be seen that, whenever one of the segments *f* comes in contact with the brush *k*, the circuit including the receiver R is completed and the condenser discharged through the same. By an adjustment of the speed of rotation to the cylinder *d* and a displacement of the brush *k* along the cylinder the circuit may be made to open and close in as rapid succession, and remain open or closed during such intervals of time, as may be desired.

The plates P and P^1, through which the electrical energy is conveyed to the brushes a and a^1, may be at a considerable distance from each other in the ground, or one in the ground and the other in the air, preferably at some height. If but one plate is connected to the earth and the other maintained at an elevation, the location of the apparatus must be determined with reference to the position of the stationary waves established by the generator, the effect evidently being greatest in a maximum, and zero in a nodal region. On the other hand, if both plates be connected to earth, the points of connection must be selected with reference to the difference of potential, which it is desired to secure, the strongest effect being, of course, obtained when the plates are at a distance equal to half the wave-length.

In illustration of the operation of the system, let it be assumed that alternating electrical impulses from the generator are caused to produce stationary waves in the earth, as above described, and that the receiving apparatus is properly located with reference to the position of the nodal and ventral regions of the waves. The speed of rotation of the cylinder C^2 is varied until it is made to turn in synchronism with the alternate impulses of the generator, and the position of the brushes b and b^1 is adjusted by angular displacement, or otherwise, so that they are in contact with the segments S and S^1 during the periods when the impulses are at, or near, the maximum of their intensity. These requirements being fulfilled, electrical charges of the same sign will be conveyed to each of the terminals of the condenser, and with each fresh impulse it will be charged to a higher potential. The speed of rotation of the cylinder d being adjustable at will, the energy of any number of separate impulses may thus be accumulated in potential form and discharged through the receiver R upon the brush k coming in contact with one of the segments f. It will be understood, that the capacity of the condenser should be such as to allow the storing of a much greater amount of energy than is required for the ordinary operation of the receiver. Since by this amount a relatively great amount of energy, and in suitable form, may be made available for the operation of a receiver, the latter need not be very sensitive. But, when the impulses are very weak, or when it is desired to operate a receiver very rapidly, any of the well-known sensitive devices, capable of responding to very feeble influences, may be used in the manner indicated or in other ways.

Under the conditions described it is evident that during the continuance of the stationary waves, the receiver will be acted upon by current impulses more or less intense, according to its location with reference to the maxima and minima of said waves, but upon interrupting or reducing the flow of the current the stationary waves will disappear or diminish in intensity. Hence a great variety of effects may be produced in a receiver according to the mode, in which the waves are controlled. It is practicable, however, to shift the nodal and ventral regions of the waves at will from the sending station, as by varying the length of the waves under observance of the above requirements. In this manner the regions of maximum and minimum effect may be made to coincide with any receiving station or stations. By impressing upon the earth two or more oscillations of different wave-length a resultant "stationary" wave may be made to travel slowly over the globe, and thus a great variety of useful effects may be produced. Evidently, the course of a vessel may be easily determined without the use of a compass, as by a circuit connected to the earth at two points, for the effect exerted upon the circuit will be greatest when the plates P P^1 are lying on a meridian passing through ground plate E, and will be *nil* when the plates are located at a parallel circle. If the nodal and ventral regions are maintained in fixed positions the speed of a vessel carrying a receiving apparatus may be exactly computed from observations of the maxima and minima regions successively traversed. This will be understood when it is stated, that the projections of all the nodes and loops on the earth's diameter passing through the pole, or axis of symmetry of the wave-movement, are all equal. Hence in any region at the surface the wave length can be ascertained from simple rules of geometry. Conversely, knowing the wave-length, the distance from the source can be readily calculated. In like ways the distance of one point from another, the latitude and longitude, the hour, *etc.*, may be determined from the observation of such stationary waves. If several such generators of stationary waves—preferably of different lengths—were installed in judiciously selected localities, the entire globe could be sub-divided in definite zones of electric activity and such and other important data could be at once obtained by simple calculation or readings from suitably graduated instruments.

The specific plan of producing the stationary waves, herein described, might be departed from. For example, the circuit which impresses the powerful oscillations upon the earth might be connected to the latter at two points.

In collecting the energy of these disturbances in any terrestrial region at a distance from their source, for any purpose, and, more especially, in appreciable amounts, the most economical results will be generally secured by the employment of my synchronized receiving transformer. This invention forming part of my system of transmission of energy through the natural media, has been fully explained in the patents first cited here, but for the better understanding of the present description it is diagrammatically illustrated in Fig. 3. Its most essential part is a circuit E^1 C^1 D^1 which is connected, arranged and adjusted similarly to the transmitting circuit E C D and which is inductively linked with a secondary circuit A^1. The latter, it scarcely need be stated, may be wound with any desired number of turns, such as will be best suited for the operation of the device designated by M. The receiving transformer is closely attuned to the oscillations of the transmitting circuit so that, irrespective of the length of the conductor E^1 C^1 A^1, the points of maximum potential coincide with the elevated terminal D^1, under which conditions the greatest amount of wave energy may be collected and rendered available in the secondary circuit A^1 for useful purposes.

To complete this description, it may be stated that when it is desired to operate, independently, a great many receiving devices, by such stationary waves of different lengths, the principles which I have set forth in my British Patent 14,579 (1901) and in my United States Patents Nos. 723,188 and 725,605 (1903) may be resorted to for rendering the signals or quantities of energy intended for any particular receiver or receivers non-interfering and non-interferable.

In the above, I have briefly outlined my discovery and indicated only a few uses of the same, but it will be readily seen, that it is of transcending importance for the advancement of many arts and industries, new and old, and capable of innumerable valuable applications.

Having now particularly described and ascertained the nature of this invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

1. The improvement in the art of transmitting electrical energy to a distance which consists in establishing stationary electrical waves in the earth, as set forth.

2. A system in accordance with Claim 1 which consists in establishing in the natural conducting media, stationary electrical waves of predetermined length and operating thereby one or more receiving devices remote from the source of energy and properly located with respect to the position of such waves as herein set forth.

3. The improvement in the art of transmitting electrical energy, which consists in producing in the earth stationary electrical waves of different lengths,

varying their lengths, and causing thereby a resultant wave or effect to travel with the desired velocity over the earth, as above described.

4. The method of producing effects at a distance, which consists in impressing upon the terrestrial globe stationary electrical waves, varying their characteristics and relations, and causing thereby corresponding effects in distant receivers, as above described.

5. The improvement in the art of transmitting and distributing electrical energy, which consists in producing in the terrestrial globe intersecting trains of stationary electrical waves, establishing thereby regions of definite electrical activities, and collecting the energy, as above set forth.

6. The method of producing electrical effects increasing with the distance which consists in impressing upon the earth electrical oscillations of a frequency of about six per second and of such character as to give rise to a stationary electrical wave, as set forth.

7. The method of producing great electrical movements in the terrestrial globe, which consists in rendering it resonant by impressing upon it electrical waves of definite length and duration, as above specified.

8. In the system as hereinbefore described for the transmission of electrical energy, generating apparatus adapted for producing a resonant condition in the terrestrial globe, as above specified.

9. In the system as hereinbefore described for the transmission of electrical energy, a transformer adapted for the production of great electrical movements in the terrestrial globe, as above specified.

10. In the system as hereinbefore described for the transmission of electrical energy, a source of primary electrical oscillations such as a condenser circuit and a secondary circuit inductively linked with the same and adapted for throwing the terrestrial globe into resonance, as above specified.

Dated this 17th day of April, 190

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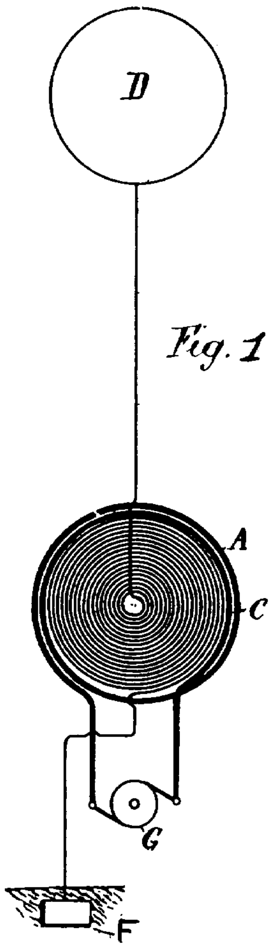
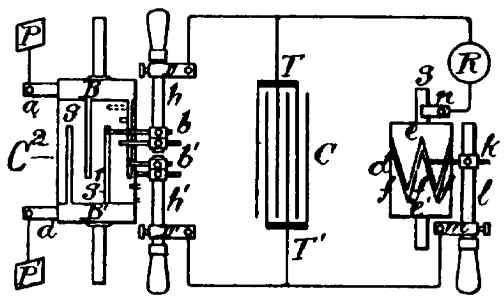


Fig. 1

Fig. 2



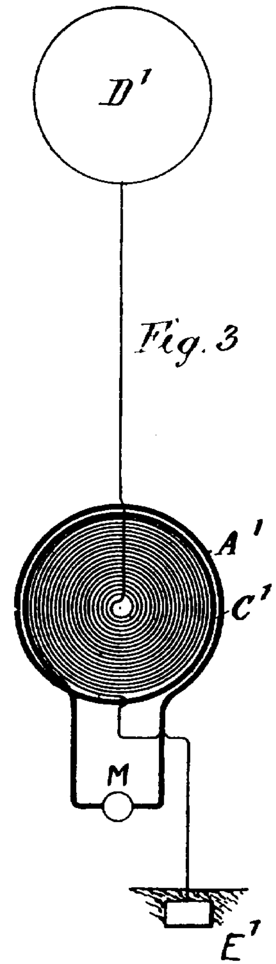


Fig. 3

N° 8575 A.D. 1891

Date of Application, 19th May, 1891—Accepted 20th June, 1891

COMPLETE SPECIFICATION.

Improved Methods of and Apparatus for Generating and Utilizing Electric Energy for Lighting Purposes.

I, NIKOLA TESLA, of the Gerlach, 45 West 27th Street, New York, United States of America, Electrician, do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement:—

My invention consists in a novel method of, and apparatus for producing light by electricity, as hereinafter described.

Electric currents of very great frequency or of very short duration and also electric currents of very great difference of potential have heretofore been produced for various purposes, but I have discovered that results of the most useful character may be secured by means of electric currents in which both the above described conditions of great frequency and great difference of potential are present. In other words, I have found that an electrical current of an excessively small period and very high potential may be utilized economically and practically to great advantage for the production of light, and I would here make it clear that I refer now to a current or what may be termed an electrical effect, of a rapidity of oscillation or alternation far in excess of anything that has heretofore been considered desirable or perhaps possible under practical working conditions, and of a potential greater, perhaps, than has ever been developed and applied to any useful purpose, and this will be more fully disclosed by the description of the nature of the invention which is hereinafter given.

The carrying out of this invention and the full realization of the conditions necessary to the attainment of the desired results involve, first a novel method of and apparatus for producing the currents or electrical effects of the character described, second, a novel method of utilizing and applying the same for the production of light, and third, a new form of translating device or light giving appliance.

To produce a current of very high frequency and very high potential, certain well-known devices may be employed. For instance, as the primary source of current or electrical energy a continuous current generator may be used, the circuit of which may be interrupted with extreme rapidity by mechanical devices, or, a magneto-electric machine specially constructed to yield alternating currents of very small period may be used, and in either case should the potential be too low, an induction coil may be employed to raise it. Or, finally in order to overcome the mechanical difficulties, which in such cases become practically insuperable before the best results are reached, the principle of the disruptive discharge may be utilized. By means of this latter plan a much greater rate of change in the current is produced, and the invention, though not limited to this plan, will be illustrated by a description of the same.

The current of high frequency, therefore, that is necessary to the successful working of the invention is produced by the disruptive discharge of the accumulated energy of a condenser maintained by charging the said condenser from a suitable source of current and discharging it into or through a circuit under proper relations of self-induction, capacity resistance and period in the well understood ways. Such a discharge is known to be, under proper conditions, intermittent or oscillating in character, and in this way a current varying in strength at an enormously rapid rate may be produced.

Having produced in the above manner a current of excessive frequency, I obtain from it, by means of an induction coil, enormously high potentials. That is to say, in the circuit through which or into which the disruptive discharge of the condenser takes place, I include the primary of a suitable induction coil, and by a second: coil of much longer and finer wire I convert to currents of extremely hi potentials. The differences in the length of the primary and secondary coils, connection with the enormously rapid rate of change in the primary current, yi a secondary of enormous frequency and excessively high potential.

Such currents are not, so far as I am aware, available for use in the usual wa: But I have discovered that if I connect to either of the terminals of the seconda coil or source of current of high potential the leading-in wires of such a devi for example, as an ordinary incandescent lamp, that the carbon may be brought and maintained at incandescence, or, in general, that any body capable of cc ducting the high tension current described and properly enclosed in a rarefied exhausted receiver may be rendered luminous or incandescent, either wh connected directly with one terminal of the secondary source of energy or placed the vicinity of such terminals so as to be acted upon inductively.

Without attempting a detailed explanation of the causes to which tl phenomenon may be ascribed, it is sufficient to state, that assuming the mc generally accepted theories of scientists to be correct, the effects thus produc are attributable to molecular bombardment, condenser action and electric or ether disturbances.

Whatever part each or any of these causes may play in producing the effec noted, it is, however, a fact that a strip of carbon, or a mass of any other sha either of carbon or any more or less conducting substance in a rarefied or exhaust receiver and connected directly or inductively to a source of electrical energy su as described, may be maintained at incandescence if the frequency and potential the current be sufficiently high. It may be here stated that by the ter "currents of high frequency and high potential" and similar expressions used this description is not meant necessarily, currents in the usual acceptance of tl term, but, generally speaking, electrical disturbances or effects such as would l produced in the secondary source by the action of the primary disturbance electrical effect.

It is necessary to observe in carrying out this invention that care must be tak to reduce to a minimum, the opportunity for the dissipation of the energy from tl conductors, intermediate to the source of current and the light-giving body. F this purpose the conductors should be free from projections and points and we covered or coated with a good insulator.

The body to be rendered incandescent should be selected with a view to i capability of withstanding the action to which it is exposed without being rapidl destroyed, for some conductors will be much more speedily consumed than others.

In the accompanying drawing,

Figure 1 is a diagram of one of the special arrangements which I employ fc carrying my invention into practice.

Figures 2, 3 and 4 are vertical sectional views of modified forms of light-givin devices that I have devised for use with the improved system.

As all of the apparatus herein shown, with the exception of the special forms lamp, is or may be of well-known construction and in common use for oth purposes, it is indicated mainly by conventional representations.

G is the primary source of current of electrical energy. I have explained abov how various forms of generator might be used for this purpose, but in the preser illustration I assume that G is an alternating current generator of comparativel low electro-motive force. Under such circumstances, I raise the potential of th current by means of an induction coil having a primary P and secondary S Then, by the current developed in this secondary, I charge a condenser C, an this condenser I discharge through or into a circuit A having an air gap *a*, o in general, means for maintaining a disruptive discharge.

By the means above described, a current of enormous frequency is produce My object is next to convert this into a working circuit of very high potentia for which purpose I connect up in the circuit A the primary P^1 of an inductio coil having a long fine wire secondary S^1. The current in the primary P^1 develops in the secondary S^1 a current or electrical effect of corresponding frequency but of enormous difference of potential, and the secondary S^1 thus becomes the source of the energy to be applied to the purpose of producing light.

The light-giving devices may be connected to either terminal of the secondary S^1. If desired, one terminal may be connected to a conducting wall W of a room or space to be lighted, and the other arranged for connection of the lamps therewith. In such case the walls should be coated with some metallic or conducting substance in order that they may have sufficient conductivity. The lamps or light-giving devices may be an ordinary incandescent lamp, but I prefer to use specially designed lamps, examples of which I have shown in detail in the drawing. This lamp consists of a rarefied or exhausted bulb or globe which encloses a refractory conducting body, as of carbon, of comparatively small bulk and any desired shape. This body is to be connected to the secondary by one or more conductors sealed in the glass as in ordinary lamps, or is arranged to be inductively connected thereto. For this last named purpose the body is in electrical contact with a metallic sheet in the interior of the neck of the globe and on the outside of said neck is a second sheet which is to be connected with the source of current. These two sheets form the armatures of a condenser and by them the currents or potentials are developed in the light-giving body. As many lamps of this or other kinds may be connected to the terminal of S^1 as the energy supplied is capable of maintaining at incandescence.

In Figure 3 *b* is a rarefied or exhausted glass globe or receiver in which is a body of carbon or other suitable conductor *e*. To this body is connected a metallic conductor *f* which passes through and is sealed in the glass wall of the globe outside of which it is united to a copper or other wire *g* by means of which it is to be electrically connected to one pole or terminal of the source of current.

Outside of the globe the conducting wires are protected by a coating of insulation *h* of any suitable kind, and inside the globe the supporting wire is enclosed in and insulated by a tube or coating *k* of a refractory insulating substance, such as pipe clay or the like. A reflecting plate *l* is shown applied to the outside of the globe *b*.

This form of lamp is a type of those designed for direct electrical connection with one terminal of the source of current.

But, as above stated, there need not be a direct connection, as the carbon, or other illuminating body, may be rendered luminous by inductive action of the current thereon, and this may be brought about in several ways. The preferred form of lamp for this purpose, however, is shown in Figure 2.

In this figure the globe *b* is formed with a cylindrical neck within which a tube or sheet *m* of conducting material on the side and over the end of a cylinder or plug *n* of any suitable insulating material. The lower edges of this tube are in electrical contact with a metallic plate *o* secured to the cylinder *n*, all the exposed surfaces of such plate and of the other conductors being carefully coated and protected by insulation. The light-giving body *e* in this case a straight stem of carbon, is electrically connected with the said plate by a wire or conductor similar to the wire *f*, Figure 3, which is coated in like manner with a refractory insulating material *k*.

The neck of the globe fits into a socket composed of an insulating tube or cylinder *p* with a more or less complete metallic lining *s*, electrically connected by a metallic head or plate *r* with a conductor *g* that is to be attached to one pole of the source of current. The metallic lining *s* and the sheet *m* thus compose the plates or armatures of a condenser.

If a lamp be made with two carbons or refractory conductors insulated from each other, they may be connected to opposite terminals or poles of the generator and both rendered luminous. In Figure 4 such a lamp is shown. There are two strips or bodies of carbon *e* and e^1 each connected with a conducting wire *f* sealed in the glass. Inside the globe which is exhausted to the highest possible degree the wires *f* are surrounded by short tubes or cups *t*, the lower parts of which, when the wires and carbons join, are filled with a carbon paste to maintain a good electrical connection between the same. Over this is a filling of fire clay *v* or similar refractory insulating material.

The carbon strips although not in contact will both become luminous when connected respectively to the two terminals of a source of current such as above described. In this as in the forms of lamp previously described the carbons in lieu of being directly, may be inductively connected with the source of current.

This invention is not limited to the special means described for producing the results hereinbefore set forth, for it will be seen that various plans and means of producing currents of very high frequency are known, and also means for producing very high potentials, but I have only described herein certain ways in which I have practically carried out the invention.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed I declare that what I claim is :—

1. The herein described improvement in electric lighting, which consists in generating or producing for the operation of the lighting devices currents of enormous frequency and excessively high potential, substantially as herein described.

2. The method of producing an electric current for practical application, such as for electric lighting, which consists in generating or producing a current of enormous frequency and inducing by such current, in a working circuit or that to which the lighting devices are connected, a current of corresponding frequency and excessively high potential as above set forth.

3. The method of producing an electric current for practical application, such as for electric lighting, which consists in charging a condenser by a given current, maintaining an intermittent or oscillatory discharge of the said condenser through or into a primary circuit and producing thereby in a secondary working circuit in inductive relation to the primary very high potentials as above set forth.

4. The method of producing electric light by incandescence, by electrically or inductively connecting a conductor enclosed in a rarefied or exhausted receiver to one of the poles or terminals of a source of electric energy or current of a frequency and potential sufficiently high to render the said body incandescent, as above set forth.

5. A system of electric lighting, consisting in the combination with a source of electric energy or current of enormous frequency and excessively high potential of an incandescent lamp or lamps consisting of a conducting body enclosed in a rarefied or exhausted receiver and connected directly or inductively to one pole or terminal of the source of energy, as above set forth.

6. In a system of electric lighting, the combination with a source of currents of enormous frequency and excessively high potential of incandescent lighting devices each consisting of a conducting body enclosed in a rarefied or exhausted receiver, the said conducting body being connected directly or inductively to one pole or terminal of the source of current, and a conducting body or bodies in the vicinity of said lighting devices connected to the other pole or terminal of said source, as above set forth.

7. In a system of electric lighting, the combination with a source of currents of enormous frequency and excessively high potential, of lighting devices each consisting of a conducting body enclosed in a rarefied or exhausted receiver and connected by conductors directly or inductively with one of the terminals of said source, all parts of the conductors intermediate to the said source and the light-giving body being insulated and protected to prevent the dissipation of the electric energy, as herein set forth.

8. An electric lamp, consisting of a rarefied or exhausted globe, a refractory conducting body contained therein and a supporting conductor therefor adapted to be directly or inductively connected with a source of current.

9. An electric lamp, consisting of a rarefied or exhausted globe, two strips or bodies of refractory conducting material contained therein, and supporting conductors adapted to connect the said strips or bodies respectively to the opposite poles of a source of current, as above set forth.

Dated this 19th day of May 1891.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, W.C., Agents for the Applicant.

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Fig. 1

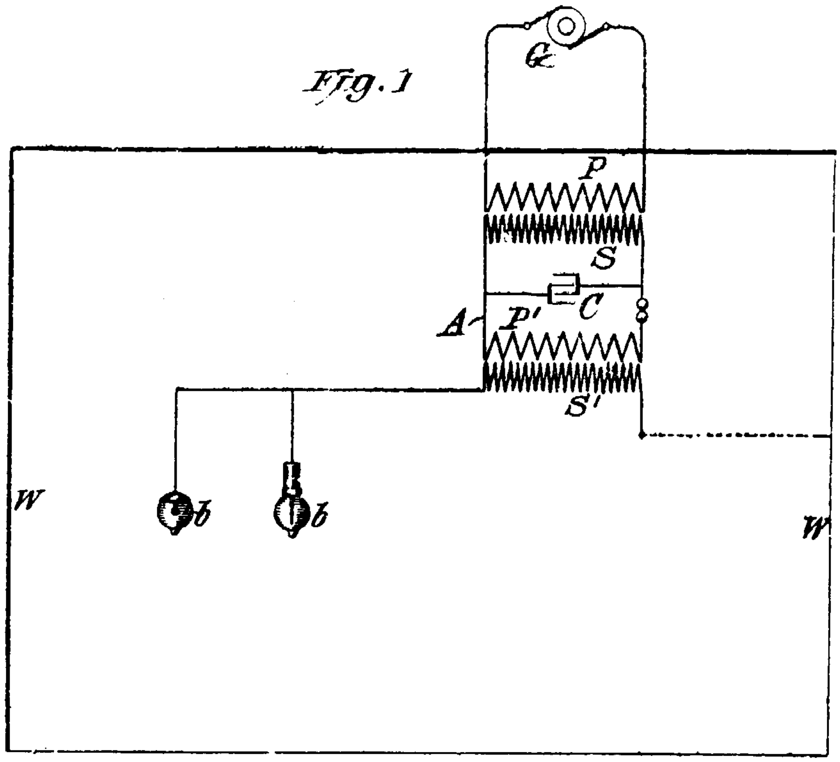


Fig. 2

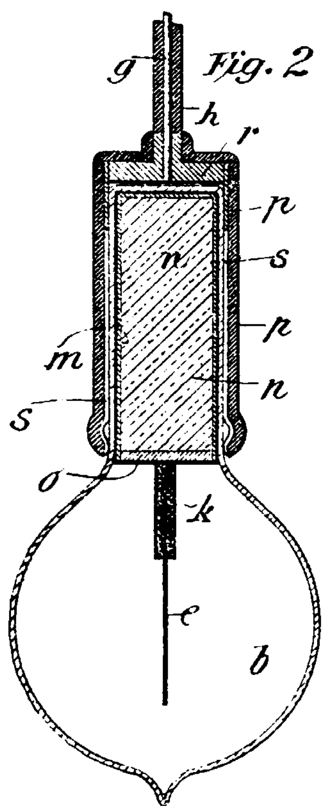


Fig. 3

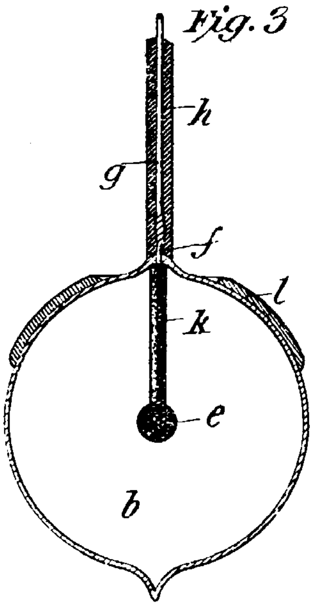
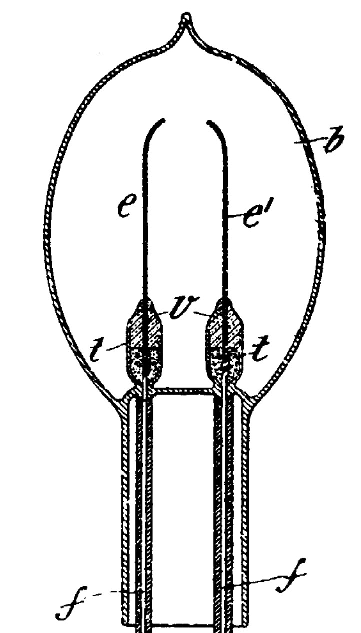


Fig. 4



No 11,293 A.D. 1901

Date of Application, 1st June, 1901—Accepted, 2nd Nov., 1901

COMPLETE SPECIFICATION.

Communicated from abroad by NIKOLA TESLA of 46 East Houston Street New York United States of America Electrician.

"Improvements relating to the Utilization of Electromagnetic, Light, or other like Radiations Effects or Disturbances transmitted through the Natural Media and to Apparatus therefor."

I, HENRY HARRIS LAKE, of the Firm of Haseltine, Lake & Co., Patent Agents, 45 Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The subject of the present invention is an improvement in the art of effecting or controlling the operation of receiving apparatus by means of effects transmitted from a distance through the natural media, and it consists in a novel method of and apparatus for collecting or receiving such effects, and utilizing them for various purposes.

The invention is particularly useful in systems of signalling in which distant receiving devices are operated by means of electrical disturbances produced by proper transmitters and conveyed to such receiving devices through the natural media, but it involves, among other things, the employment of apparatus of novel character, which may be used for other purposes, such, for example, as the investigation or utilization of terrestrial solar, or other disturbances, produced by natural causes.

Several ways or methods of developing and transmitting electrical disturbances through the natural media and utilizing the same to operate distant receivers are now known, and have been applied with more or less success for accomplishing a variety of useful results.

One of these ways consists in producing, by a suitable apparatus, rays or radiations, that is, disturbances which are propagated in straight lines through space, directing them upon a receiving or recording apparatus at a distance, and thereby bringing the latter into action. This method is the oldest and best known, and has been brought particularly into prominence in recent years through the investigations of Heinrich Hertz.

Another method consists in passing a current through a circuit, preferably one enclosing a very large area, inducing thereby in a similar circuit situated at a distance, another current, and producing by the latter in any convenient way, the operation of a receiving device.

Still another way, which has also been known for many years is to pass, in any suitable manner, a current through a portion of the ground, as by connecting to two points of the same, preferably at a considerable distance from each other, the two terminals of the generator, and to energize, by a part of the current diffused through the earth, a distant circuit which is similarly arranged and grounded at two points widely apart, and which is made to act upon a sensitive receiver.

These various methods have their limitations, one especially which is common to all being that the receiving circuit or instrument must be maintained in a definite position with respect to the transmitting apparatus, a requirement which often imposes great disadvantages upon the use of the apparatus. In the course of extended investigations of the phenomena connected with this general subject, I have discovered other methods of accomplishing results of this nature which may be briefly described as follows:

In one system the potential of a point or region of the earth is varied by imparting to it intermittent or alternating electrifications through one of the terminals of a suitable source of electrical disturbances, which, to heighten the effect, has its other terminal connected to an insulated body, preferably of large surface and at an elevation. The electrifications communicated to the earth spread in all directions through the same, reaching a distant circuit which, generally, has its terminals arranged and connected similarly to those of the transmitting source, and operates upon a highly sensitive receiver.

Another method is based upon the fact that the atmospheric air, which behaves as an excellent insulator to currents generated by ordinary apparatus, becomes a conductor under the influence of currents or impulses of enormously high electromotive force which I have devised means for generating. By such means air strata which are easily accessible, are rendered available for the production of many desired effects, even at great distances.

Obviously whatever method be employed, it is desirable that the disturbances produced by the transmitting apparatus should be as powerful as possible. Furthermore, since in most cases the amount of energy conveyed to the distant circuit is but a minute fraction of the total energy emanating from the source, it is necessary for the attainment of the best results that, whatever the character of the receiver and the nature of the disturbances, as much as possible of the energy conveyed should be made available for the operation of the receiver, and I have heretofore employed, among other means, a receiving circuit of high self induction and very small resistance, and of a period such as to vibrate in synchronism with the disturbances whereby a number of separate impulses from the source were made to co-operate, thus magnifying the effect exerted upon the receiving device. By these means decided advantages have been secured in many instances, by very often the plan is either not applicable at all, or, if so, the gain is very slight.

Evidently, when the source is one producing a continuous pressure or delivering impulses of long duration, it is impracticable to magnify the effects in this manner, and, when, on the other hand, it is one furnishing short impulses of extreme rapidity of succession, the advantage obtained in this way is insignificant owing to the radiation and the unavoidable frictional waste in the receiving circuit. These losses reduce greatly both the intensity and the number of the co-operating impulses, and, since the initial intensity of each of these is necessarily limited, only an insignificant amount of energy is thus made available for a single operation of the receiver.

As this amount is consequently dependent on the energy conveyed to the receiver by one single impulse, it is evidently necessary to employ either a very large and costly, and, therefore, objectionable transmitter, or else to resort to the equally objectionable use of a receiving device too delicate and too easily deranged. Furthermore, the energy obtained through the co-operation of the impulses is in the form of extremely rapid vibrations and, because of this, unsuitable for the operation of ordinary receivers, the more so as this form of energy imposes narrow restrictions in regard to the mode and time of its application to such devices.

To overcome these and other limitations and disadvantages which have heretofore existed in systems of this character, particularly when used for the transmission of signals or intelligence, the methods and apparatus herein described have been devised for the purpose of intensifying the effects of the transmitted disturbances in order that they might be more readily detected and more efficiently utilized.

The method generally stated may be carried out by the storage of energy either from the original source of the disturbances, or from an independent source, and by the utilization of such stored energy to operate a receiving device. In one case the method is practised by producing arbitrarily varied or intermittent disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving station, utilizing the energy derived from the same at the receiving station to charge a condenser, and using the accumulated potential energy so obtained to operate a receiving device. In another case the stored energy from an independent source is used under the control of the effects or disturbances transmitted through the natural media for operating the receiving device, while a third plan, based upon the property which certain radiations, such as those of ultra-violet light, cathodic or Roentgen rays and the like possess of charging and discharging electric conductors, consists in charging one of the armatures of a condenser by such rays or radiations, and the other by an independent means, and discharging the condenser through a suitable receiver.

The general principles underlying the invention and the construction and mode of operation of the devices which are or which may be used in carrying out the invention, will be understood by reference to the accompanying drawing, in which

Figure 1 is a diagrammatic illustration of the apparatus employed when the energy from the transmitting source is to be stored.

Figure 2 is a diagrammatic illustration of the apparatus employed when the stored energy is obtained from an independent source and merely controlled by the effects transmitted.

Figure 3 is a diagram of a modified arrangement of apparatus for the same purpose, and

Figure 4 is a similar illustration of an apparatus for simultaneously charging a condenser by means of rays or radiations and an independent source of electrical energy, and discharging it through a receiver.

Referring now to Figure 1: At any two points in the transmitting medium between which there exists or may be obtained in any manner, through the action of the disturbances or effects to be utilized or investigated, a difference of electrical potential of any magnitude, I arrange two plates or electrodes 1 2 so that they may be oppositely charged through the agency of such effects or disturbances, and I connect these electrodes to the terminals of a highly insulated condenser 3, generally of considerable capacity. To the condenser terminals there is also connected the receiver 4, in series with a device of suitable construction which performs the function of periodically discharging the condenser through the receiver at and during such intervals of time as may be best suitable for the purpose contemplated. This device may consist merely of two stationary electrodes separated by a feeble dielectric layer of minute thickness, or it may comprise terminials, one or more of which are movable, and actuated by any suitable force, so as to be brought into and out of contact with each other in any convenient manner.

The special device shown for this purpose consists of a cylinder 5, made partly of conducting and partly of insulating material 6 and 7, respectively, which is rotated at the desired rate of speed by any suitable means. The conducting part 6 is in good electrical connection with the shaft 8, and is provided with tapering segments 9, upon which slides a brush 10 supported on a conducting rod 11 capable of longitudinal adjustment in a metallic support 12. Another brush 13 is arranged to bear upon the shaft 8, and it will be seen that wherever one of the segments 9 comes in contact with the brush 10 the circuit, including the receiver 4, is completed and the condenser discharged through the same. By an adjustment of the speed of rotation of the cylinder 5 and a displacement of the brush 10 along the cylinder, the circuit may be made to open and close in as rapid succession, and to remain open or closed during such intervals of time, as may be desired.

It will be readily seen that if the disturbances, of whatever nature they may be, cause definite amounts of electricity, of the same sign, to be conveyed to each of the plates or electrodes 1 and 2, *ie* definite amounts of positive electricity to one & of negative to the other either continuously or at intervals of time which are sufficiently long, the condenser will be charged to a certain potential, and, an adequate amount of energy being thus stored during the time determined by the discharging device, the receiver will be periodically operated by the electrical energy so accumulated.

But very often the character of the impulses and the conditions of their use are such that, without further provision, not enough potential energy would be accumulated in the condenser to operate the receiving device. This is the case when, for example, each of the plates or terminals 1 2 receives quantities of electricity of rapidly changing sign, or even when each receives quantities of electricity of the same sign, but only during periods which are short as compared with the intervals separating them. In such instances, the use of a special device is resorted to, which device is inserted in circuit between the plates 1 2 and the condenser 3, for the purpose of conveying to each of the terminals of the latter electrical charges of the proper quality and order of succession to enable the required amount of potential energy to be stored in the condenser.

One form of such device, which will serve for purposes of illustration of this feature of the invention, consists of a cylinder 14 of insulating material which is moved at a uniform rate of speed by clock-work or other suitable motive power, and is provided with two metal rings 15 16, upon which bear brushes 17 and 18, respectively, and which are connected in the manner shown to the two terminal plates 1 and 2. From the rings 15 16 extend narrow metallic segments 19 and 20, which, by the rotation of the cylinder 14 are brought alternately into contact with double brushes 21 and 22, carried by and in contact with conducting holders 23 and 24, which are adjustable longitudinally in the metallic supports 25 and 26 as shown. The latter are connected to the terminals 27 and 28 of the condenser 3, and it should be understood that they are capable of angular displacement as ordinary brush supports. The object of using two brushes in each of the holders is to vary at will the duration of the electric contact of the plates 1 and 2 with the terminals of the condensers.

The plates 1 and 2, through which the electrifications are conveyed to the brushes 17 and 18, may be at a considerable distance from each other, and both in the ground or both in the air, or one in the ground and the other in the air, preferably at some height, or they may be connected to conductors extending to some distance, or to the terminals of any kind of apparatus supplying electrical energy which is obtained from the energy of the impulses or disturbances transmitted from a distance through the natural media.

In illustration of the operation of the devices described, let it be assumed that alternating electrical impulses from a distant generator, are transmitted through the earth, and that it is desired to utilize these impulses in accordance with the present invention. This may be the case, for example, when such a generator is used for purposes of signalling in one of the ways above stated, as by having its terminals connected to two points of the earth distant from each other. In this case the plates 1 2 are first connected to two properly selected points of the earth; the speed of rotation of the cylinder 14 is varied until it is made to turn in synchronism with the alternate impulses of the generator, and finally, the position of the brushes 21 and 22 is adjusted so that they are in contact with the segments 19 and 20 during the periods when the impulses are at or near the maximum of their intensity.

Only ordinary electrical skill and knowledge are required to make these adjustments, and a number of devices for effecting synchronous movement being well known, a detailed description of such devices is not considered necessary. The above requirements being fulfilled, electrical charges of the same sign will be conveyed to each of the condenser terminals as the cylinder 14 is rotated, and with each fresh impulse the condenser will be charged to a higher potential. The speed of rotation of the cylinder 5 being adjustable at will, the energy of any number of separate impulses may thus be accumulated in potential form and discharged through the receiver 4 upon the brush 10 coming in contact with one of the segments 9. It will be of course understood that the capacity of the condenser should be such as to allow the storing of a much greater amount of energy than is required for the ordinary operation of the receiver. Since by this method a relatively great amount of energy and in a suitable form may be made available for the operation of a receiver, the latter need not be very sensitive, but of course, when the impulses are very feeble, as when coming from a great distance, or when it is desired to operate a receiver very rapidly, then any of the well known devices capable of responding to very feeble influence may be used in this connection.

If instead of alternating impulses short impulses of the same direction are conveyed to the plates 1 and 2, the apparatus described may still readily be used, and for this purpose it is merely necessary to shift the brushes 21 and 22 while maintaining the same condition with regard to synchronism as before, so that the succeeding impulses will be permitted to pass into the condenser, but prevented from returning to the ground or transmitting medium during the intervals between them, owing to the interruption during such intervals of the connections leading from the condenser terminals to the plates.

Another way of using the apparatus with impulses of the same direction is to take off one pair of brushes, as 21, disconnect the plate 1 from the brush 17 and join it directly to the terminal 27 of the condenser, and to connect brush 17 with brush 18. Operated in this manner, and assuming the speed of rotation of cylinder 14 to be the same, the apparatus will now be adapted for a number of impulses per unit of time twice as great as in the preceding case. In all cases it is evidently important to adjust the duration of contact of segments 19 and 20 with brushes 21 and 22 in the manner indicated.

When the method and apparatus described are used for the purpose of transmitting signals or intelligence, the transmitter, it will be understood, is operated in such a way as to produce disturbances or effects which are varied or intermitted in some arbitrary manner, for example, to produce longer and shorter successions of impulses corresponding to the dashes and dots of a telegraph code, and the receiving device will respond to, and indicate, these variations or intermittances, since the storage device will be charged and discharged a number of times corresponding to the duration of the successions of impulses received.

In the form of apparatus for utilizing the stored energy of an independent source, and which is illustrated in Figures 2 and 3, a charging circuit is connected to the terminals 27 and 28 of the condenser 3, and includes a battery 30, a sensitive device 31, and a resistance 32, all connected in series, as shown. The battery should be of very constant electromotive force and of an intensity carefully determined to secure the best results. The resistance 32, which may be a frictional or an inductive one, is not absolutely necessary, but it is of advantage to use it in order to facilitate adjustment, and for this purpose it may be made variable in any convenient manner.

If the disturbances which are to be utilized or investigated are rays identical with or resembling those of ordinary light, the sensitive device 31 may be a selenium cell properly prepared so as to be highly susceptible to the influence of the rays, the action of which should be intensified by the use of a reflector 33. It is well known that when cells of this kind are exposed to such rays of greatly varying intensity, they undergo corresponding modifications of their electrical resistance, but in the ways they have heretofore been used they have been of very limited utility.

In addition to the circuit including the sensitive device or cell, 31, another circuit is provided which is likewise connected to the terminals 27 and 28 of the condenser. This circuit is the same as that described in connection with

Figure 1 and contains a receiver 4 and a device 5 for periodically discharging the condenser through the receiver.

It will be noted that, as shown in Figure 2, the receiving circuit is in permanent connection with the battery and condenser terminal 27, but it is sometimes desirable to entirely insulate the receiving circuit at all times, except at the moments when the device 5 operates to discharge the condenser, thus preventing any disturbing influences which might otherwise be caused in this circuit by the battery or the condenser during the period when the receiver should not be acted upon. In such a case two devices as 5 may be used, one in each connection from the condenser to the receiving circuit, or else one single device of this kind, but of suitably modified construction, so that it will make and break simultaneously and at proper intervals, both connections.

From the foregoing the operation of the apparatus will be understood. Normally, that is, when not influenced by the rays, or very slightly so, the cell 31, being of comparatively high resistance, permits only a relatively feeble current to pass from the battery into the condenser, and hence the latter is charged at too slow a rate to accumulate, during the time interval between two succeeding operations of the device 5, sufficient energy to operate the receiver. This condition is readily secured by a proper selection and adjustment of the various devices described, so that the receiver will remain unresponsive to the feeble discharges of the condenser which may take place when the cell 31 is acted upon but slightly, or not at all, by the rays or disturbances. But if now new rays are permitted to fall upon the cell, or if the intensity of those already acting upon it be increased by any cause, then its resistance will be diminished and the condenser will be charged by the battery at a more rapid rate, enabling sufficient potential energy to be stored in the condenser during the period of inaction of the device 5, to operate the receiver or to bring about any desired change in the receiving circuit when the device 5 acts. If the rays acting upon the cell or sensitive device 31 are varied or intermitted in any arbitrary manner, as when transmitting intelligence in the usual way from a distant station by means of short and long signals, the apparatus may readily be made to record, or to enable an operator to read the message, since the receiver, supposing it to be an ordinary electro-magnetic relay, for example, will be operated by each signal from the sending station a certain number of times having some relation to the duration of each signal. It will be readily seen, however, that if the rays are varied in any other way, as by impressing upon them changes in intensity, the succeeding condenser discharges will undergo corresponding changes in intensity which may be indicated or recorded by a suitable receiver, and distinguished irrespective of duration.

The electrical connections of the various devices illustrated may be made in various ways. For instance, the sensitive device, instead of being in series with, as shown, may be a shunt to the condenser, and in this case the condenser will store less energy when the sensitive device is energized by the rays and its resistance thereby diminished. The adjustment of the various instruments will then be such that the receiver will be operated only when the rays are diminished in intensity, or interrupted and entirely prevented from falling upon the sensitive cell.

The sensitive device may also be placed in shunt to the resistance 32, as well as to the condenser, or the several instruments may be connected in the manner of a Wheatstone bridge, as hereinafter described, but in each case the sensitive device operates to control the energy stored and utilized in some suitable way for actuating the receiver. The condenser may be replaced by other means of storage without departure from the invention.

In Figure 3 I have shown a more complete arrangement of the apparatus, particularly adapted for the investigation or utilization of very feeble impulses or disturbances, such as may be used in conveying signals or producing other desired effects at great distances. In this case the energy stored in the condenser 3 is passed through the primary 34 of a transformer, the secondary 35 of which is in a circuit containing the receiver 4. In order to render the apparatus still more suitable for use in detecting feeble impulses, in addition to the sensitive device 31 which is acted upon by the transmitted impulses, another such device 36 is included in the secondary circuit of the transformer.

The plan of connections is, in the main, that of a Wheatstone bridge, the four branches of which are formed of the sensitive device 31 and resistances 37, 38 and 39, all of which should be preferably inductive and adjustable in a continuous manner. The condenser is connected to two opposite points of the bridge, while a battery 30, in series with a continuously adjustable non-inductive resistance 32, is connected to the other pair of opposite points as usual. The four resistances 31, 37, 38 and 39 are so proportioned that under normal conditions, or when the device 31 is not influenced at all, or only slightly by the disturbances, there will be no difference of potential or, in any case the minimum of the same, at the terminals 27 and 28 of the condenser.

It is assumed in the present instance that the disturbances are such as will produce a difference of electrical potential, however small, between two points in the earth or air. and, in order to apply this potential difference effectively the terminals of the sensitive device are as in Figure 1, two plates, 1 and 2, located at a suitable distance apart. Any form of sensitive device may be employed, that shown being one of familiar construction and consisting of an insulating tube having its ends closed by two conducting plugs with extensions upon which bear brushes 40, through which currents are conveyed to the device. The tubular space between the plugs is partially filled with a conducting sensitive powder. This tube is to be rotated by suitable clock work or otherwise at a uniform rate of speed, under which conditions it behaves towards disturbances of the kind now under consideration in a manner similar to that of a stationary cell of selenium towards rays of light. Its electrical resistance is diminished when it is acted upon by the disturbances and is automatically restored upon cessation of their influence.

The primary 34 is usually of few turns and low resistance, and is in circuit with a discharger 5 of the kind hereinbefore described.

The secondary coil 35 is usually of much finer wire and of many more turns. In circuit therewith is the receiver 4, shown as an ordinary relay; a continuously adjustable non-inductive resistance 41, a battery 42, of a properly determined and very constant electro-motive force and the sensitive device 36 of the same construction as that above described.

The electro-motive force of the battery 42 is so graduated by means of the adjustable resistance 41 that the dielectric layers in the sensitive device 36 are strained very nearly to the point of breaking down, and give way upon a slight increase of the electrical pressure on the terminals of the device. It will of course be understood that other means than the resistances 32 and 41 may be employed for securing the proper adjustment of the apparatus.

The various instruments being connected and adjusted in the manner described, the periodical closing of the primary circuit of the transformer by means of the device 5 will have no appreciable effect so long as the sensitive device 31 remains unaffected. But when, owing to the disturbances or impulses propagated through the media from a distant source, an additional electro-motive force, however small, is created between the terminals of the device 31, the dielectric layers give way and allow the current of the battery 30 to pass through, thus causing a difference of potential at the terminals 27, 28 of the condenser 3. A sufficient amount of energy being now stored in this instrument during the time interval between each two succeeding operations of the device 5, each closure of the primary circuit by the latter results in the passage of a sudden current impulse through the coil 34, which induces a corresponding current of relatively high electro-motive force in the secondary coil 35. This breaks down the resistance of the sensitive device 36 and allows the current of battery 42 to pass and to operate the receiver 4, but only for a moment, since by the rotation of the devices 5, 31 and 36, which may all be driven from the same shaft, the original conditions are restored, assuming, of course, that the electro-motive force set up by the disturbances at the terminals of the sensitive device 31 is only momentary, or of a duration not longer than the time of closure of the primary circuit; otherwise the receiver will be actuated a number of times, and so long as the influence of the disturbances upon the device 31 continues.

In order to render the discharged energy of the condenser more effective in causing the operation of the receiver, the resistance of the primary circuit should be very small and the secondary coil 35 should have a number of turns many times greater than that of the primary coil 34. It is preferable to make the inductive resistances 37 and 38 relatively large, as they are in a shunt to the device 31, and might, if made too small, impair its sensitiveness.

In Figure 4, which illustrates the third method or plan above referred to, 43, represents an insulated plate or conducting body which is to be exposed to the action of rays or radiations, and 44 another plate, the two being connected in series with the condenser 3. The terminals 27 and 28 of the latter are also connected to a circuit containing a receiver 4, and a circuit controlling device which, in this case, is composed of two very thin conducting plates 45, 46, placed in close proximity and very mobile, either by reason of extreme flexibility or owing to the character of their support. To improve their action they should be enclosed in a receptacle, from which the air may be exhausted. The receiver 4 is shown as consisting of an electro-magnet and armature, a retractile spring and a ratchet wheel 47, provided with a spring pawl 48, which is pivoted to the armature as shown. The terminal 44 may be connected to one of the poles of a battery or other source of electricity, or it may itself be, or be connected with any conducting body or object of such properties, or so conditioned, that by its means electricity of the required sign will be supplied to the terminal.

A simple way of supplying positive or negative electricity to the terminal is to connect the same either to an insulated conductor supported at some height in the atmosphere, or to a grounded conductor, the former, as is well known furnishing positive, the latter negative electricity.

The apparatus being arranged as shown, it will be found that when the radiations of the sun or of any other source capable of producing the effects described, fall upon the plate 43 an accumulation of energy in the condenser 3 will result. This phenomenon, I believe, is best explained as follows: The sun, as well as other sources of radiant energy, throws off minute particles of matter positively electrified, which, impinging upon the plate 43, communicate an electrical charge to the same. The opposite terminal of the condenser being connected to the ground, which may be considered as a vast reservoir of negative electricity, a feeble current flows continuously into the condenser and, inasmuch as these supposed particles are of an inconceivably small radius or curvature and consequently charged to a relatively very high potential, this charging of the condenser may continue, as I have found in practice, almost indefinitely, even to the point of rupturing the dielectric. Obviously, whatever circuit controller be employed, it should operate to close the circuit, in which it is included when the potential in the condenser has reached the desired magnitude.

By carefully observing well known rules of design and adjustment of the instruments, the several forms of apparatus above described may be made extremely sensitive and capable of responding to the faintest influences, thus making it possible to utilize impulses or disturbances transmitted from very great distances and too feeble to be detected or utilized in any of the ways heretofore known, and on this account the invention lends itself to many scientific and practical uses of great value.

It is evident that, since one of the chief requirements which the invention herein described is designed to meet is the detection and utilization of feeble transmitted effects, many of the improvements which have been illustrated are also applicable to ordinary telegraphic and telephonic systems involving the use of artificial lines, and such applications I regard as within the scope of my invention and claims.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

1. The method of utilizing effects or disturbances transmitted from a distance through the natural media, which consists in storing the energy derived from such effects or controlling thereby the storage of energy from an independent source, and using the accumulated energy so obtained to operate a receiving device.

2. The method of utilizing effects or disturbances transmitted from a distance through the natural media, which consists in charging therewith or controlling thereby the charging of a condenser and discharging the accumulated energy through a receiving device.

3. The method of utilizing effects or disturbances transmitted from a distance through the natural media, which consists in charging therewith or effecting thereby the charging of a condenser during any desired time intervals, and discharging the accumulated energy for periods of time predetermined as to succession and duration, through a receiving device.

4. The method herein described of producing arbitrarily varied or intermitted electrical disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving station, establishing thereby a flow of electrical energy in a circuit at such station, charging a condenser with electrical energy from such circuit and discharging the accumulated potential energy so obtained into or through a receiving device at arbitrarily predetermined intervals of time.

5. The method herein described of producing arbitrarily varied or intermitted electrical disturbances or effects, transmitting such disturbances or effects through the natural media to a distant receiving station, establishing thereby a flow of energy in a circuit at such station, selecting and directing the impulses in said circuit so as to render them suitable for charging a condenser, charging a condenser with the impulses so selected or directed and discharging the accumulated potential energy so obtained into or through a receiving device.

6. The method and apparatus described herein and illustrated in Figure 4, by which a condenser is simultaneously charged by rays or radiations and an independent means and discharged through a suitable receiver, either automatically by the accumulated energy or by other means, suitably controlled.

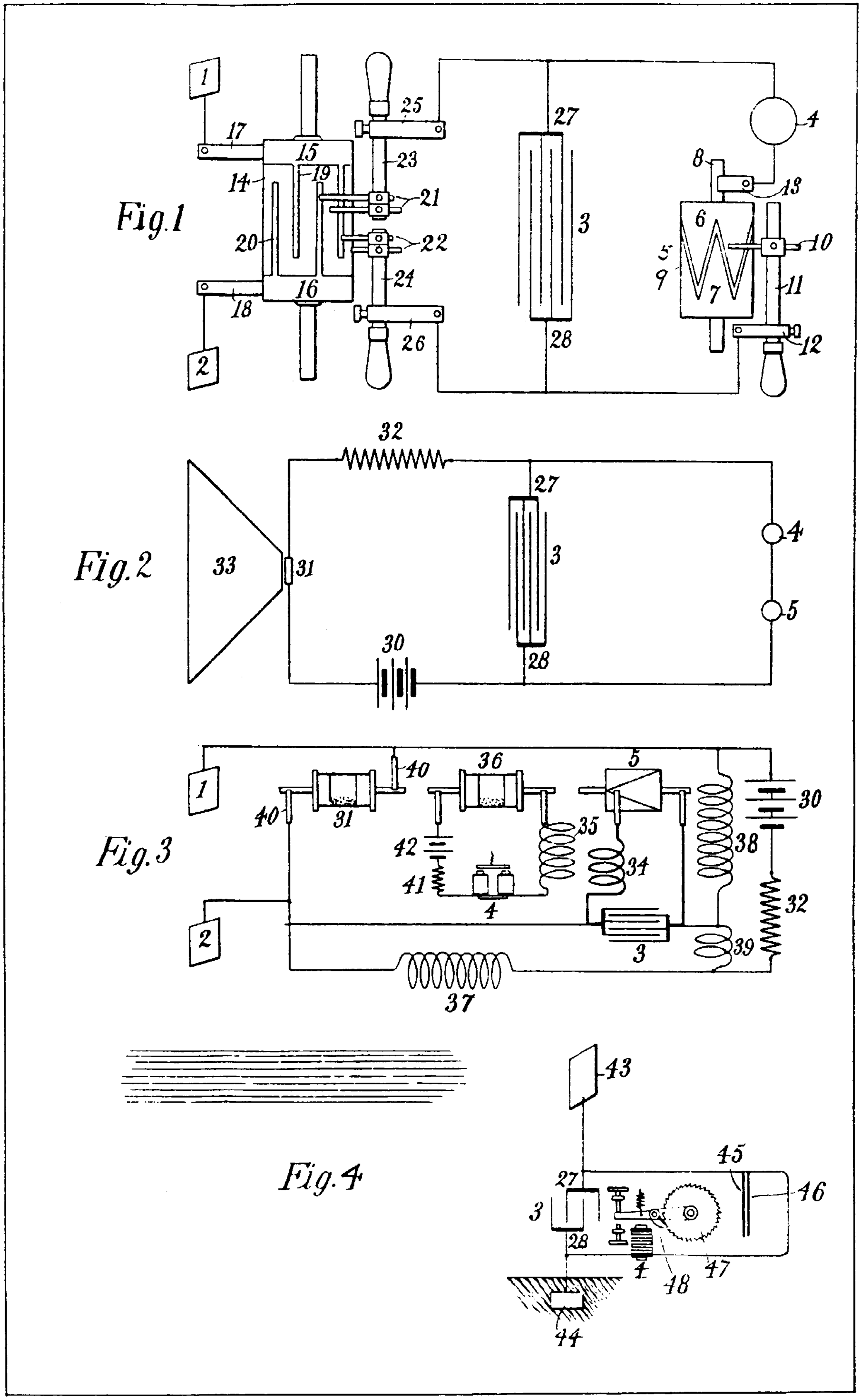
7. The apparatus herein described and illustrated in Figure 1, for receiving and selecting when necessary electrical impulses transmitted through the natural media from a distant source, charging a condenser and discharging the same through a receiver, as set forth.

8. The apparatus herein described and illustrated in Figures 2 and 3, for controlling the charging of a condenser from an independent source, by means of effects or disturbances transmitted from a distance through the natural media, and discharging the same through a condenser.

Dated this 1st day of June 1901.

HASELTINE LAKE & Co.
45 Southampton Buildings, London, W.C., Agents for the Applicant.

Redhill: Printed for His Majesty's Stationery Office, by Malcomson & Co., Ltd.—1901.



[This Drawing is a reproduction of the Original on a reduced scale.]

Malby & Sons, Photo-Litho.

Nº 11,473 A.D. 1891

Date of Application, 6th July, 1891—Accepted, 22nd Aug., 1891

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of Astor House, New York, United States of America, Electrician.]

Improvements in Alternating Current Electro-magnetic Motors.

I, HENRY HARRIS LAKE, of the firm of Haseltine Lake & Co., Patent Agents, 45 Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed to be particularly described and ascertained in and by the following statement :—

This invention relates to electric motors, the action or operation of which is dependent upon the inductive influence upon, and magnetization of a rotating armature by independent field magnets or coils traversed by alternating or similar currents, which produce their effect upon said armature not simultaneously but successively, as would result from said currents being of different phase.

The improvements consist in a novel arrangement applicable to motors, in which the current for one of the energizing circuits is obtained by induction from the other, and also in a means for increasing the flow of current in the closed induced armature coils of any form of alternating current motor in which such coils may be present, particularly, in what are now known as the Tesla motors.

The first feature above referred to is the placing in the secondary or induced field or energizing circuit of the motor a condenser, adjusting it so as to neutralize the self induction to the desired extent, and to secure between the primary and the secondary currents the proper difference of phase for the most economical operation of the motor; and the second is the interposition of a condenser in the induced or what is otherwise the closed circuit of the armature.

In the accompanying drawings

Figure 1 is a form of induction motor to which the improvements are applied.

Figure 2 is a diagram of a modification of a part of the improvements.

The motor is composed of two or more pairs or sets of field magnets, A and B, mounted in or forming part of a suitable frame and a rotary armature wound with a coil C.

In the particular motor here shown, the coils on two opposite poles, as A, are connected directly to a main or branch circuit D from a generator of alternating currents. Over, or in any other inductive relation to these coils, secondary coils E are wound, and in the circuit of these are included the energizing coils F of the other pair of field poles B. Hence, the alternating currents that energize the poles A, induce currents that energize poles B, but no means have heretofore been proposed that would secure between the phases of the primary or inducing and the secondary or induced currents that difference of phase, theoretically ninety degrees, that is best adapted for practical and economical working.

To more perfectly secure this object, I interpose in the secondary circuit, or that which includes the coils E, F, a condenser G, adjusting it as to capacity in well-known ways so as to neutralize or overcome the retarding effect of self induction and bring the phase more nearly to the proper point of difference.

As the required capacity of this condenser is dependent upon the rate of alternation or the potential or both, its size and cost may be brought within economical limits, for use with the ordinary circuits by raising the potential of the secondary circuit in the motor. Many turns of fine wire are therefore used for the coils E, so as to convert to a current of very high potential.

This improvement is equally applicable to motors of this type, that is to say,—

those in which the currents for one energizing circuit are induced from the other when a distinct transformer outside of the motor is used. In the illustration, the two energizing circuits are brought into inductive relation inside the motor, but it is evident that they may be brought into the same relation outside the motor by means of a transformer.

In this, as well as in all other forms of motor in which a closed armature coil is used, in which currents are induced by the action of the field magnets or coils, the most efficient working conditions require, that, for a given inductive effect upon the armature there should be the greatest possible current through the armature or induced coils, and, also, that there should always exist between the currents in the energizing and the induced circuits, a given relation or difference of phase hence, whatever tends to decrease the self-induction and increase the current in the induced circuit will, other things being equal, increase the output and efficiency of the motor, and the same will be true of causes that operate to maintain the mutual attractive effect between the field magnets and armature at its maximum.

These results are secured by connecting with the induced or armature circuit H of the armature a condenser L. This coil or coils H have no connection with the outside circuit and are closed upon themselves through the condenser. In ordinary cases, the terminals of the coils lead to collecting rings M, M, upon which brushes N, N, bear, and the condenser is inserted between these brushes. But the armature core may be hollow and the condenser carried within it, or the sheet-iron plates, of which the core is composed, may be carefully insulated so as to constitute a condenser, and the coils may be connected to the plates. In such cases no brushes would be required.

The condenser should be of such character as to overcome the self-induction of the armature, so that when the motor is in operation the impedence of the said coils to the passage of the induced currents is not only neutralized, but the phases of the induced currents are brought more nearly into proper accord with those in the field coils.

In motors in which the armature coils are closed upon themselves, as, for example, in any form of alternating current motor in which one armature coil or set of coils is in the position of maximum induction with respect to the field coils or poles, while the other is in the position of minimum induction, the coils are preferably connected in one series and two points of the circuit thus formed are bridged by a condenser. This is illustrated in Figure 2, in which P represents one set of armature coils and P^1 the other. Their points of union are joined through a condenser G.

It will be observed that in this disposition the self-induction of the two branches P and P^1 varies with their position relatively to the field magnet, and that each branch is alternately the predominating source of the induced current, hence the effect of the condenser G is two-fold. Firstly, it increases the current in each of the branches alternately and secondly it alters the phase of the currents in the branches, this being the well-known effect which results from such a disposition of a condenser with a circuit as above described.

This effect is favorable to the proper working of the motor because it increases the flow of current in the armature circuits due to a given inductive effect, and also because it brings more nearly into coincidence the maximum magnetic effects of the co-acting field and armature poles.

Although this feature of the invention has been illustrated herein, in connection with a special form of motor, it will be understood that it is equally applicable to any other alternating current motor in which there is a closed armature coil wherein the currents are induced by the action of the field, and, furthermore, I would state also that the feature of utilizing the plates or sections of a magnetic core for forming the condenser, I regard as applicable, generally, to other kinds of alternating current apparatus.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is :—

First. In an alternating current motor in which one energizing circuit is in inductive relation to the other and closed upon itself, the combination with such closed or secondary circuit of a condenser interposed in the same, as described.

Second. In an alternating current motor, the combination of two energizing circuits, one connected or adapted for connection with a source of alternating currents, the other constituting a secondary circuit in inductive relation to the first and adapted to convert to currents of high potential, and a condenser interposed in the said secondary circuit, as set forth.

Third. In an alternating current motor, the combination with the armature and an energizing circuit formed by a coil or conductor wound thereon in inductive relation to the field, of a condenser connected to the said coil or conductor.

Fourth. In an alternating current motor, the combination with armature coils in inductive relation to the field and connected in a closed circuit, of a condenser bridging said circuit, as set forth.

Fifth. In an alternating current motor, the combination with the induced energizing coil or coils of the armature of a condenser connected therewith and made a part of the armature or rotating element of the motor.

Dated this 4th day of July 1891.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, W.C., Agents for the Applicant.

London: Printed for Her Majesty's Stationery Office, by Darling & Son, Ltd.—1891

1 SHEET

Fig. 1

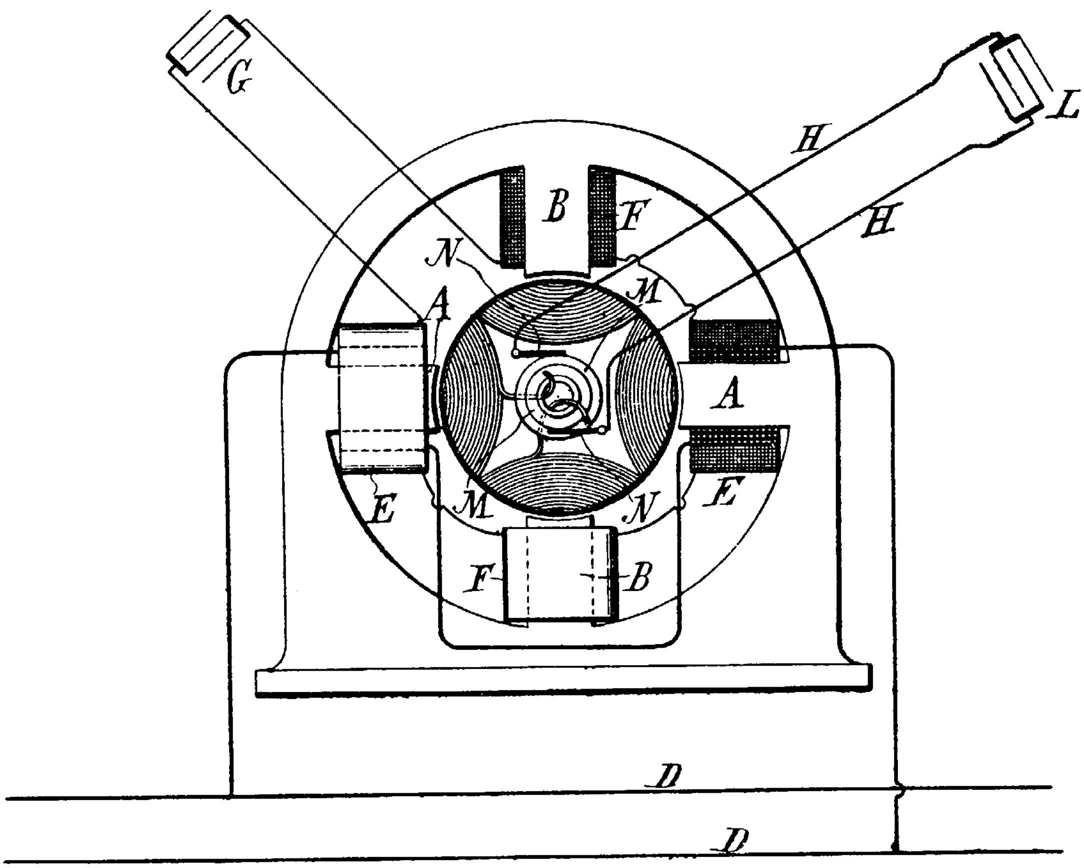
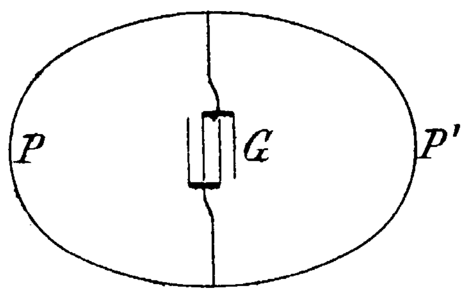


Fig. 2



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LONDON. Printed by DARLING and SON Ld.
for Her Majesty's Stationery Office 1891

Malby & Sons, Photo-Litho.

N° 12,866 A.D. 1898

Date of Application, 8th June, 1898—Accepted, 27th Aug., 1898

COMPLETE SPECIFICATION.

[Communicated from abroad by Nikola Tesla, of 46, East Houston Street, Borough of Manhattan, New York, United States of America, Electrician.]

Improvements in Electrical Circuit Controllers.

I, Henry Harris Lake, of the Firm of Haseltine, Lake & Co., Patent Agents, 45, Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

I have heretofore invented and patented methods and apparatus for the generation, conversion and utilization of electrical currents of very high frequency based upon the principle of charging a condenser, and discharging the same, generally through the primary of a transformer, the secondary of which constituted the source of working currents, and under such conditions as to yield a vibrating or rapidly intermittent current.

In some of the forms of apparatus which I have heretofore devised for carrying out the methods referred to, I have employed a mechanism for making and breaking an electric circuit or branch thereof for the purpose of charging and discharging the condenser, and the present application is based upon a novel and improved type of a circuit controller or device for this purpose. The principles of construction and operation of the apparatus designed in accordance with this invention will be understood from the following statement of the nature of its requirements and mode of use.

In every device which makes and breaks an electric circuit with any considerable degree of abruptness, a waste of energy occurs during the periods of make or break, or both, due to the passage of the current through an arc formed between the receding or approaching terminals or contacts, or, in general, through a path of high resistance. The tendency of the current to persist after the actual disjunction or to precede the conjunction of the terminals exists in varying degrees in different forms of apparatus, according to the special conditions present. For example, in the case of an ordinary induction coil, the tendency to the formation of an arc at the break is, as a rule, the greater, while in certain forms of apparatus for utilizing the discharge of a condenser, such as heretofore referred to, this tendency is greatest at the instant immediately preceding the conjunction of the contacts of the circuit controller which effects the discharge of the condenser.

The loss of energy occasioned by the causes mentioned may be very considerable, and is generally such as to greatly restrict the use of the circuit controller and render impossible a practical and economical conversion of any considerable amounts of electrical energy by its means, particularly in cases in which a high frequency of the makes and breaks is required.

Extended experiment and investigation, conducted with the aim of discovering a means for avoiding the loss incident to the use of ordinary forms of circuit controllers, have led me to recognize certain laws governing this waste of energy and which show it to be dependent, chiefly, on the velocity with which the terminals approach and recede from one another and also more or less on the form of the current wave. Briefly stated, from both theoretical considerations and practical experiment, it appears that the loss of energy in any device for making and breaking a circuit, other conditions being the same, is inversely proportional rather to the square than to the first power of the speed or relative velocity of the terminals in approaching and receding from one another, in any instance in which the current wave is not so steep as to materially depart from one which may be represented as a sine function of the time.

But such a case seldom obtains in practice; on the contrary, the current curve resulting from a make and break is generally very steep, and particularly so when, as in my system, the circuit controller effects the charging and discharging of a condenser, and consequently the loss of energy is still more rapidly reduced by an increased velocity of approach and separation of the terminals. The demonstration of these facts and the recognition of the impossibility of attaining the desired results by using ordinary forms of circuit controllers, have led me to invent the novel apparatus for making and breaking a circuit, which in several modified forms is made the subject of the present application.

Various devices for making and breaking an electric current have heretofore been used or proposed in which the separable contact points or terminals were contained in an exhausted vessel or surrounded by an inert atmosphere, but there are certain theoretical conditions necessary for complete success, which I have recognized and which have not been attained by the means heretofore employed. These may be summed up as follows:

(1) The medium by which the contact points are surrounded should have as high an insulating quality as possible, so that the terminals may be approached to an extremely short distance before the current leaps across the intervening space.

(2) The closing up or repair of the injured dialectric, or in other words, the restoration of the insulating power, should be instantaneous, in order to reduce to a minimum the time during which the waste principally occurs.

(3) The medium should be chemically inert so as to diminish as much as possible the deterioration of the electrodes and to prevent chemical processes which might result in the development of heat, or in general, in loss of energy.

(4) The giving way of the medium under the application of electrical pressure should not be of a yielding nature, but should be very sudden, and in the nature of a crack, similar to that of a solid, such as a piece of glass, when squeezed in a vice;

(5) And most important, the medium ought to be such that the arc, when formed, is restricted to the smallest possible linear dimensions and is not allowed to spread or expand.

As a step in the direction of these theoretical requirements I have heretofore employed in some of my circuit controlling devices a fluid of high insulating qualities, such as liquid hydro-carbon, and caused the same to be forced, preferably, with great speed, between the approaching and receding contact points of the circuit controller. By the use of such liquid insulation a very marked advantage was secured, but while some of the above requirements were attained in this manner, certain defects still existed, notably that due to the fact that the inslating liquid, in common with a vacuous space, though in a lesser degree, permits the arc to expand in length and thickness, and to thus pass through all degrees of resistance, thereby causing a greater or less waste of energy.

To overcome this defect and to still more nearly attain the theoretical conditions required for most efficient working of the circuit controlling devices, I have been finally led to use a gaseous insulating medium subjected to great pressure.

The application of great pressure to the medium in which the make and break are made, secures a number of special advantages. One of these may be obviously inferred from well-established experimental facts, which demonstrate that the striking distance of an arc is, approximately, inversely proportional to the pressure of the gaseous medium in which it occurs. But in view of the fact that in most cases occurring in practice the striking distance is very small, since the differences of potential between the electrodes are usually not more than a few hundred volts, the economical advantages resulting from the reduction of the striking distance, particularly on the approach of the terminals, are not of very great practical consequence. By far the more important gain I have found to result from a novel effect which I have observed to follow from the action of such a medium when under pressure, upon the arc, namely, that the cross-section of the latter is reduced approximately in an inverse ratio to the pressure. As under conditions, in other respects the same, the waste of energy in an arc is proportional to the cross-section of the latter, a very important gain in economy generally results. A feature of great practical value lies also in the fact that the insulating power of the compressed medium is not materially impaired even by considerable increase in temperature, and, furthermore, that variations of pressure between wide limits, if the apparatus is properly constructed, do not interfere notably with the operation of the circuit controller. In many other respects, however, a gas under great compression, nearly fulfils the ideal requirements above mentioned, as in the sudden breaking down and quick restoration of the insulating power, and also in chemical inertness which, by proper selection of the gas, is easily secured.

In applying this feature of my invention the medium under pressure may be produced or maintained in any proper manner, the improvement not being limited in this particular to any special means for the purpose. I prefer, however, to secure the desired result by confining the circuit controller, or at least so much of the same as shall include the terminals, in a closed chamber or receptacle with rigid walls, with the interior of which communicates a small reservoir containing a liquified gas.

Referring now to the accompanying drawings for a more detailed description of the apparatus,

Fig. 1 is a diagram illustrating the general arrangement of the circuit controller and the special manner in which it is designed to be used.

Fig. 2 is a top plan view of the circuit controller.

Fig. 3 is a view partly in section and partly in elevation of the complete apparatus indicated diagrammatically in Fig. 1.

The remaining figures are central sectional views of modified forms of the apparatus, with the exception of Fig. 10, which is a sectional plan view of the upper portion of the form of apparatus shown in Fig. 9.

The general scheme of the system for use with which the improved circuit controller is more especially designed, will be understood by reference to Fig. 1. In said figure X, X represent the terminals of a source of current. A^1 is a self induction or choking coil included in one branch of the circuit and permanently connected to one side of a condenser A^{11}. The opposite terminal of this condenser is connected to the other terminal of the source through the primary A^3 of a transformer, the secondary A^4 of which supplies the working circuit containing any suitable translating devices, as A^5.

The circuit controller A which is represented conventionally, operates to make and break a bridge from one terminal of the source to a point between the choking coil A^1 and the condenser A^{11}, from which it will result that when the circuit is completed through the controller, the choking coil A^1 is short circuited and stores energy, which is discharged into the condenser when the controller circuit is broken, to be in turn discharged from the condenser through the primary A^3, when the said condenser and primary are short circuited by the subsequent completion of the controller circuit.

Figs. 2 and 3 illustrate a typical form of the circuit controller. The parts marked A, B, compose a closed receptacle of cylindrical form having a dome or extension of smaller diameter. The receptacle is secured to the end of a spindle a which is mounted vertically in bearings of any character suitable for the purpose.

Rapid rotation is imparted to the receptacle in any suitable manner, as by means of a field magnet a^1 secured to the base or frame, and an annular armature a^{11} secured to the receptacle A. The coils of the armature are connected with the plates c of a commutator secured to the receptacle A and made in cylindrical form so as to surround the socket in which the spindle a is stepped.

A body of magnetic material c^1 which serves as an armature is mounted on anti-friction bearings on an extension of the spindle a so that the receptacle and the body c^1 may have freely independent movements of rotation.

Surrounding the dome B in which the armature is contained is a core with pole pieces c^{11}, which are magnetized by coils b wound on the core. The said core is stationary, being supported by arms b^1, Fig. 2, independently of the receptacle, so that when the receptacle is rotated and the core energized, the attractive force exerted by the poles c^{11} upon the armature c^1 within the receptacle A holds the said armature against rotation. To prevent loss from currents set up in the shell of the dome B, the latter should be made of German silver or other similar precaution taken.

An arm b^{11} is secured to the armature c^1 within the receptacle A and carries at its end a short tube d bent as shown in Fig. 2, so that one end is tangential to the receptacle wall, and the other directed towards the center of the same.

Secured to the top plate of the receptacle A are a series of conducting plates d^1. The part of the top plate d^{11} from which said conducting plates depend, is insulated from the receptacle proper by insulating packing rings, but is electrically connected with the dome B, and in order to maintain electrical connection from an external circuit to the conductors d^1 a mercury cup e is set in the top of the dome, into which cup extends a stationary terminal plug e^1.

A small quantity of a conducting fluid, such as mercury, is put into the receptacle A and when the latter is rotated, the mercury, by centrifugal action, is forced out towards the periphery and rises up along the inner wall of the receptacle. When it reaches the level of the open mouthed tube d, a portion is taken up by the latter which is stationary, and forced by its momentum through the tube and discharged against the conductors d^1 as the latter pass in rapid succession by the orifice of said tube.

In this way the circuit between the receptacle and the conductors d^1 is completed during the periods in which the stream or jet of mercury impinges upon any of the said conductors and broken whenever the stream is discharged through the spaces between them.

The feature of my invention which consists in maintaining an atmosphere of inert gas under pressure in the receptacle containing the circuit controller is applicable to all of the forms of circuit controller herein described. A special arrangement for the purpose, however, is shown in Fig. 4, which exhibits also a modified arrangement of the circuit controlling mechanism designed to overcome the objection which in some cases might lie to such forms as those of Figs. 2 and 3 from the amount of work which the conducting fluid is required to perform at very high speeds.

Referring to Fig. 4, the receptacle A has a head B secured by a gas-tight insulating joint. A spindle C is screwed or otherwise secured centrally in the head B and on this is mounted on antifriction bearings a sleeve D to which rotary motion may be imparted in any suitable manner, as by securing to said sleeve D a laminated magnetic core a^1 and placing around the portion of the head B which contains it a core a^{11} provided with coils and constituting the primary element of a motor capable of producing a rotary field of force which will produce a rapid rotation of the secondary element or core a^1.

To the depending end of the sleeve D is secured a conducting disk D^1 with downwardly extending teeth or projections d^1.

To the sleeve or to the disk D^1 is also attached, but insulated therefrom, a shaft D^{11} having a spiral blade E^1 and extending down into a well or cylindrical recess in the bottom of the receptacle.

One or more ducts or passages E lead from the bottom of this well to points near the path of the conducting teeth of the disk D^1 so that by the rotation of the screw E^1 the conducting fluid will be forced up through the duct or ducts from which it issues in a jet or jets against the rotating conductor.

To facilitate this operation, the well is surrounded by a flange E^{11} containing passages e^{11} which permit the conducting fluid to flow from the receptacle into the well, and having bevelled sides which serve as a shield to deflect the fluid expelled from the ducts through the spaces in the conductor to the bottom of the receptacle.

Any suitable reservoir M is placed in communication with the interior of the main receptacle and partially filled with a liquified gas which maintains a practically inert atmosphere under pressure in the receptacle. Preferably, though mainly as a matter of convenience, the reservoir M is a metal cup with a hollow central stem F^1, the opening for the passage of gas being controlled by a screw-valve in the top of the cup. The cup is screwed onto the end of the spindle C, through which is a passage F^{11} leading into the interior of the receptacle.

To insure a good electrical connection between the sleeve D and the spindle C, I provide in the former a small chamber f which contains mercury, and into which the end of the spindle C extends.

Fig. 5 illustrates a modification of the circuit controller which involves two prominent features useful in devices of this character. One, that it provides for maintaining, in a rotating receptacle, a stationary jet or jets which, by impinging on a rigid conductor, maintain the latter in rotation, thereby securing the requisite rapidly intermittent contact between the two; the other, that it utilizes the rotation of such rigid conductor as a means for opposing or preventing the movement of its own supports in the direction of rotation of the receptacle, thereby securing, among other things, an approximately constant relative movement between the parts, a feature which, in devices of this kind, is often very desirable.

In said Fig. 5 the receptacle A is provided with trunnions which have bearings in standards f^{11}, f^{11}, and which permit the rotation of the receptacle about a horizontal axis.

In the particular form of device under consideration the receptacle is divided into two parts insulated by a washer G and held together by insulated bolts G^1 with nuts G^{11}.

A body I is supported by trunnions g having bearings in the ends of the receptacle and concentric with the axis of rotation of the same. The weight of the body I, being eccentric to this axis, tends to oppose its turning about the axis when the receptacle is rotated.

Upon the body or support I, but insulated therefrom, is secured a vertical standard g^1 in which there is a freely rotatable spindle f^1 carrying a disk g^{11} with radial arms inclined to the plane of the disk so as to form vanes d^1.

Arms i, i^1 are also secured to the body I and are formed with, or carry at their ends, ducts or tubes d with one end directed towards and opening upon the vanes d^1, and the other end close to the inner wall of the receptacle and opening in the direction opposite to that of its rotation.

A suitable quantity of mercury is placed in the receptacle before the latter is sealed or closed.

The operation of the device is as follows: The receptacle is started in rotation, and, as it acquires a high velocity, the mercury or other conducting fluid is caused, by centrifugal action, to distribute itself in a layer over the inner peripheral surface.

As the tubes or ducts d do not take part in the rotation of the fluid, being held at the start by the weighted body I, they take up the mercury as soon as it is carried to the points where the ducts open, and discharge it upon the vanes of the disk g^{11}.

By this means the disk is set in rapid rotation, establishing the contact between the two sides of the receptacle which constitute the two terminals of the circuit controller whenever the two streams or jets of fluid are simultaneously in contact with the vanes, but breaking the contact whenever the jets discharge through the spaces between the vanes.

The chief object of employing two insulated jets rather than one is to secure a higher velocity of approach and separation, and in this respect the device may be still further improved by providing any number of such insulated compartments and jets and a corresponding number of rotating rigid conductors.

The disk g^{11}, having acquired a very rapid rotation, operates by gyrostatic action to prevent any tendency of the body I to rotate or oscillate, as such movement would change the plane of rotation of the disk. The movement of the parts, therefore, and the operation of the device as a whole is very steady and uniform and a material practical advantage is thereby secured. The speed of the disk will be chiefly dependent on the velocity of the streams and pitch of the blades, and it is, of course, necessary, in order to produce a constant speed of rotation of the disk, that the velocity of the streams be constant. This is accomplished by rotating the receptacle with a constant speed, but when this is impracticable and the uniformity of motion of the disk very desirable, I resort to special means to secure this result, as by providing overflowing reservoirs i^{11}, i^{11}, as indicated by dotted lines, from which the fluid issues upon the vanes with constant velocity, though the speed of the receptacle may vary between wide limits.

It will be understood that the jets which effect the electrical contact, need not necessarily be utilized to drive the disk, but that for this latter purpose additional jets may be provided and applied to an insulated portion of the disk or to a body connected therewith, in which case such jets may be made to impinge instead of upon the peripheral portions, on parts situated nearer to the axis of rotation, thus causing a more rapid movement of the disk. The jets may also be produced in many other ways.

To still further increase the rate of relative movement of the terminals, each may be rotated with respect to the other. This may be effected in various ways, of which the device shown in Fig. 6 is an example. In said figure H designates a casting of cylindrical form within which is a standard or socket in which is mounted a vertical spindle a carrying the circuit controlling mechanism.

The said mechanism is contained in a receptacle A, the top or cover of which is composed of an annular plate and a cap or dome B, the latter being of insulating material or of a metal of comparatively high specific resistance, such as German silver. Any suitable means may be employed to effect the rotation of the receptacle, the particular device shown for this purpose being an electro-magnetic motor, one element a^1 of which is secured to the spindle a or receptacle A, and the other a^{11} to the box or case H. Within the receptacle A, and secured to the top of the same, but insulated therefrom, is a circular conductor with downwardly extending projections or teeth d^1. This conductor is maintained in electrical connection with a plate H^1 outside of the receptacle by means of screws or bolts H^{11} passing through insulated gaskets in the top of the receptacle A.

Within the latter is a standard or socket h, in which is mounted a spindle h^1 concentric with the axis of the receptacle.

Any suitable means may be provided for rotating the spindle independently of the receptacle A, but for this purpose I again employ an electro-magnetic motor, one element h^{11} of which is secured to the spindle h^1 within the receptacle A, and the other j is secured to the box H and surrounds the cap or dome B, within which is mounted the armature h^{11}.

Depending from the spindle h^1 or the armature h^{11} is a cylinder, to which are secured arms b^{11}, b^{11} extending radially therefrom and supporting short tubes or ducts d between the peripheral walls of the receptacle A and the series of teeth or projections d^1.

The tubes d have openings at one end in close proximity to the inner wall of the receptacle A and turned in a direction opposite to that in which the latter is designed to rotate, and at the other end orifices which are adapted to direct a stream or jet of fluid against the projections d^1.

To operate the apparatus the receptacle A, into which a suitable quantity of mercury is first poured, and the spindle h^1 are both set in rotation by their respective motors and in opposite directions. By the rotation of receptacle A the conducting fluid is carried by centrifugal force up the sides or walls of the same and is taken up by the tubes or ducts d and discharged against the rotating conductors d^1. If, therefore, one terminal of the circuit be connected with any part of the receptacle A, or the metal portions of the instrument in electrical connection therewith, and the other terminal be connected to the plate H^1, the circuit between these terminals will be completed whenever a jet from one of the ducts d is discharged against one of the projections d^1, and interrupted when the jets are discharged through the spaces between such projections.

Instead of using a solid or rigid conductor for one of the terminals or contacts and a conducting fluid for the other, I may use a conducting fluid for both, under conditions which permit of a rapidly intermittent contact between them, as will be seen by reference to Fig. 7.

The receptacle, as shown in this figure, is composed of two parts insulated from each other and supported by trunnions so as to rotate about a horizontal axis. The abutting ends of the two parts are formed with inwardly extending flanges J^1 which divide the peripheral portion of its interior into two compartments J^{11} and K^{11}.

Into one of these compartments, as J^{11}, extends a spindle K, having its bearing in one end of the receptacle A, and the trunnion secured to or extending therefrom. Into the other compartment K^{11} extends a spindle K^1 similarly journalled in the opposite end of the receptacle A and its trunnion.

Each spindle carries or is formed with a weighted arm I, which remaining in a vertical position holds its spindle stationary when the receptacle is revolved.

To the weighted arm or spindle K is secured a standard L carrying a tube d with one open end in close proximity to the inner peripheral wall of the compartment J^{11} and the other directed towards the axis, but inclined towards the opposite compartment.

To the weighted arm or spindle K^1 is similarly secured to standard L^1 which is hollow and constitutes a portion of a duct or passage which extends through a part of the spindle and opens through a nozzle l^{11} into a circular chamber l in the wall of the receptacle. From this chamber run passages l^1 to nozzles m in position to discharge jets or streams of liquid in such directions as to intersect, when the nozzles are rotated, a stream issuing from the end of tube d.

In each portion or compartment of the receptacle is placed a quantity of mercury, and the ends of the tubes are provided with openings which take up the mercury when, on the rotation of the receptacle, it is carried by centrifugal force against the peripheral wall. The mercury when taken up by the tube d issues in a stream or jet from the inner end of said tube and is projected into the compartment K^{11}. The mercury taken up by the tube L^1 runs into the circular chamber l from which it is forced through the passages l^1 to the nozzles m from which it issues in jets or streams directed into the compartment J^{11}. As the nozzles m revolve the streams which issue from them will therefore be carried across the path of the stream which issues from the tube d and which is stationary, and the circuit between the two compartments will be completed by the streams whenever they intersect, and interrupted at all other times.

The continuity of the jets or streams is not preserved, ordinarily, to any great distance beyond the orifices from which they issue, and hence they do not serve as conductors to electrically connect the two sides of the receptacle beyond their point of intersection with each other.

It will be understood that so far as the broad feature of maintaining the terminal jets is concerned, widely different means may be employed for the purpose and that the spindles mounted in free bearings concentrically with the axis of rotation of the receptacle and held against rotation by the weighted arms constitute but one specific way of accomplishing this result. This particular plan, however, has certain advantages and may be applied to circuit controllers of this class generally whenever it is necessary to maintain a stationary or nearly stationary body within a rotating receptacle.

It is further evident, from the nature of the case that it is not essential that the jet or jets in one compartment or portion of the instrument should be stationary and the others rotating, but only that there should be such relative movement between them as to cause the two sets to come into rapidly intermittent contact in the operation of the device.

The number of jets, whether stationary or rotating, is purely arbitrary, but since the conducting fluid is directed from one compartment into the other, the aggregate amount normally discharged from the compartments should be approximately equal. However, since there always exists a tendency to project a greater quantity of the fluid from that compartment which contains the greater into that which contains the lesser amount no difficulty will be found in this respect in maintaining the proper conditions for the satisfactory operation of the instrument.

A practical advantage, especially important when a great number of breaks per unit of time is desired, is secured by making the number of jets in one compartment even and in the other odd, and placing each jet symmetrically with respect to the center of rotation. Preferably the difference between the number of jets should be one. By such means, the distances between the jets of each set are made as great as possible and hurtful short-circuits are avoided.

For the sake of illustration, let the number of jets or nozzles *d* in one compartment be nine, and the number of those marked *m* in the other compartment ten, then by one revolution of the receptacle there will be ninety makes and breaks.

To attain the same result with only one jet as *d* it would be necessary to employ ninety jets *m* in the other compartment, and this would be objectionable, not only because of the close proximity of the jets, but also of the great quantity of fluid required to maintain them.

In the use of the instrument as a circuit controller it is merely necessary to connect the two insulated parts of the receptacle to the two parts of the circuit respectively.

In instruments of this character in which both terminals are formed by a liquid element, there is no wear or deterioration of the terminals and the contact between them is more perfect. The durability and efficiency of the devices are thus very greatly increased.

I may also secure the same result by a modified form of circuit controller, in which the closure of the circuit is effected through two parts of conducting fluid, but in this case instead of breaking the circuit by the movement of these two parts or terminals, as in the device of Fig. 7, I separate them periodically by the interposition of an insulator which is preferably solid and refractory.

For example, I provide a plate or disk with teeth or projections of glass, lava or the like, which are caused by the rotation of the disk to pass through the jet or fluid conductor and thus effect a make and break of the circuit.

By means of such a device the breaks always occur between fluid terminals, and hence deterioration and consequent impairment of the qualities of the apparatus is avoided.

In Fig. 8, which shows this form of controller, the receptacle which contains the terminals is mounted on a spindle *a* in a suitable socket or support so as to rotate freely.

The means shown for rotating the receptacle are the same as in Fig. 3, although any other might be employed.

In the spindle *a*, and concentric with its axis, is a spindle M supported on ball-bearings or otherwise arranged to have a free movement of rotation relatively to the spindle *a* so as to be as little as possible influenced by the rotation of the latter.

Any convenient means is provided to oppose or prevent the rotation of the spindle M during the rotation of the receptacle. In the particular arrangement here shown for this purpose a weight or weighted arm I is secured to the spindle M, and eccentrically to the axis of the latter, and, as the bearing for the spindle *a* holds the same at an angle to the vertical, this weight acts by gravity to hold the spindle M stationary.

Secured to the top or cover of the receptacle A, by a stud m^1 which passes through an insulating bushing in said cover and is held by a nut m^{11}, is a circular disk M^1 of conducting material, preferably iron or steel, having its edge turned downwardly and then inwardly to provide a peripheral through on the underside of the disk.

To the under side of the disk M^1 is secured a second disk M^{11} having downwardly inclined peripheral projections *n*, *n*, of insulating and preferably refractory material in a circle concentric with the disk M^1.

A tube or duct *d* is mounted on the spindle M or the weight I, and is so arranged that the orifice at one end is directed outwardly towards the trough of the disk M^1 while the other lies close to the inner peripheral wall of the receptacle so that if a quantity of mercury or other conducting fluid be placed in the receptacle and the latter rotated, the tube or duct *d*, being held stationary, will take up the fluid which is carried by centrifugal action up the side of the receptacle and deliver it in a stream or jet against the trough or flange of the disk M^1 or against the inner surfaces of the projections *n* of disk M^{11}, as the case may be.

Obviously, since the two disks M^1 and M^{11} rotate with respect to the jet or stream of fluid issuing from the duct *d*, the electrical connection between the receptacle and the disk M^1 through the fluid will be completed by the jet when the latter passes to the disk M^1 between the projections *n*, and will be interrupted whenever the jet is interrupted by the said projections.

The rapidity and the relative duration of the makes and breaks is determined by the speed of rotation of the receptacle and the number and width of the intercepting projections *n*.

By forming that portion of the disk M^1 with which the jet makes contact, as a trough, which will retain, when in rotation, a portion of the fluid directed against it, a very useful feature is secured. The fluid, under the action of centrifugal force accumulates in and is distributed along the trough and forms a layer over the surface upon which the jet impinges. By this means a very perfect contact is always secured, and all deterioration of the terminal surfaces avoided.

It is not necessary that the conducting fluid which forms one of the terminals, should be in the form of a jet issuing from the orifice of a tube or duct. The same results may be secured by the use of a body or stream of the fluid maintained in rapid movement in other ways, and in Figs. 9 and 10 I have illustrated a means for accomplishing this.

The receptacle A is mounted and rotated in the case in the same manner as in Fig. 8, and a spindle M carrying an eccentric weight I is also employed.

Attached to the spindle M or weight I is an insulated bracket O carrying a standard or socket O^1 in which is mounted, on antifriction bearings, a spindle O^{11}. Secured to this latter is a plate with radial arms *o* from which depend vanes or blades o^1, with projections o^{11} extending radially therefrom. A shield or screen P encloses the vanes except on the side adjacent to the inner periphery of the receptacle A.

A small quantity of a conducting fluid is placed in the receptacle, and in order to secure a good electrical connection between the vanes o^1 and a terminal on the outside of the receptacle, a small mercury cup p in metallic contact with the vanes through the bracket O and socket O^1 is secured to the weight I. A metal stud set in an insulated bolt m^1 projects into the cup p through a packed opening in its cover. One terminal of the circuit controlling mechanism will thus be any part of the metal receptacle, and the other the insulated bolt m^1.

To operate the apparatus, the receptacle is set in rotation, and as its speed increases the mercury or other conducting fluid which it contains is carried, by centrifugal force, up the sides of the inner wall over which it spreads in a layer. When this layer rises sufficiently to encounter the projections o^{11} on the blades or vanes o^1, the latter are set in rapid rotation, and the electrical connection between the terminals of the apparatus is thereby made and broken, it may be, with very great rapidity.

The projections o^{11} are preferably placed at different heights on the vanes o^1 so as to secure greater certainty of good contact with the mercury film when in rapid rotation.

In all of the several modified forms of my improved apparatus above described, the receptacle which contains or encloses the parts or elements of the circuit controller proper, is rotated; but this is not essential, since, by proper modification of the apparatus the necessary relative movement may be secured between the terminals when contained in a stationary receptacle.

This is illustrated in Fig. 11, in which a stationary receptacle A is shown as composed of top and bottom plates of metal and a cylindrical portion of insulating material, such as porcelain. Within the receptacle, and preferably integral with the side walls, are two annular troughs W, W^1, which contain a conducting fluid, such as mercury. Terminals R, R^1, passing through the bottom of the receptacle through insulating and packed sleeves, afford a means of connecting the mercury in the two troughs with the conductors of the circuit.

Surrounding that portion of the device in which the troughs W, W^1, lie is a core A^{11} wound with coils arranged in any suitable and well-known manner to produce, when energized by currents of different phase, a rotating magnetic field in the space occupied by the two bodies of mercury. To intensify the action, a circular laminated core r is placed within the receptacle.

If by this or any other means, the mercury is set in motion and caused to flow around in the troughs, and if a conductor be mounted in position to be rotated by the mercury, and when so rotated to make intermittent contact therewith, a circuit controller may be obtained of novel and distinctive character, and capable of many useful applications independently of the other features which are embodied in the complete device which is illustrated.

For the present purpose I provide in the center of the receptacle a socket in which is mounted a spindle R^{11} carrying a disk r^1. Depending from said disk are arms r^{11} which afford bearings, for a shaft S supporting two star-shaped wheels S^1, S^{11}, arranged to make contact with the mercury in the two troughs respectively. The shaft S is mounted in insulated bearings, so that when both wheels are in contact with mercury the circuit connecting the terminals R, R^1 will be closed. The disk r^1 carries an annular core T, and coils T^1 are supported outside of the receptacle and are preferably of the same character as those used for imparting rotation to the mercury, but the direction of rotation should be opposite to that of the mercury.

The rate of rotation of the wheel S^1, S^{11} depends upon the rate of relative movement of the mercury, and hence if the mercury be caused to flow in one direction and the wheels be carried bodily in the opposite direction, the rate of rotation and consequently the frequency of the makes and breaks will be very greatly increased over that which would be obtained if the wheels S^1, S^{11} were supported in a stationary bearing.

In all the forms of circuit controller above described in which the circulation of the conducting fluid through tubes or ducts is maintained, the force which impels the fluid is derived from the same source as that which rotates the receptacle or maintains the relative movement of the terminals. In other words, instead of employing an independent pump or like device for forcing the fluid trough the ducts, I combine in one, the two mechanisms—the controller and the means for maintaining a circulation of the conducting fluid.

It will be observed that the invention involves many features which are broadly new in instruments of this character, and is not limited to the specific forms of apparatus shown and described, but may be carried out by other and widely differing forms.

Having now particularly described and ascertained the nature of this invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

1. A circuit controller comprising in combination, a receptacle containing a conducting fluid, means for rapidly rotating the receptacle or the fluid therein, and a terminal or terminals supported within the receptacle and adapted to make and break electrical connection with the fluid.

2. The combination with a receptacle of a conductor or series of spaced conductors, a nozzle or tube for directing a jet or stream of fluid against the same, the nozzle and conductor being capable of movement relatively to each other, and means for maintaining a circulation of conducting fluid, contained in the receptacle, through said nozzle, and dependent for operation upon such relative movement.

3. The combination with a closed receptacle of a conductor or series of spaced conductors, a nozzle or tube for directing a jet or stream of fluid against the same, and means for forcing a conducting fluid contained in the receptacle through the said nozzle, these parts being associated within the receptacle and adapted to be operated by the application of a single actuating power.

4. The combination with a receptacle containing a series of spaced conductors, a duct within the receptacle having one of its ends directed towards the said conductors, means for maintaining a rapid movement of relative rotation between the said end and the conductors and means for maintaining a circulation of a conducting fluid contained in the receptable through the duct against the conductors, the said conductors and jet constituting respectively the terminals or elements of an electric circuit controller.

5. The combination with a receptacle capable of rotation and containing a series of spaced conductors, a duct within the receptacle having an orifice directed towards the said conductors, and an open end in position to take up a conducting fluid from a body of the same contained in the receptacle, when the latter is rotated, and direct it against the conductors, the said conductors and the fluid constituting the terminals or elements of an electric circuit controller.

6. The combination with a receptacle for containing a conducting fluid and a series of spaced conductors therein, of a duct having an orifice directed towards the said conductors and forming a conduit through which the fluid when the receptacle is rotated is forced and thrown upon the conductors.

7. The combination with a receptacle capable of rotation, and a series of conductors mounted therein, of a duct having an orifice directed towards the conductors, a holder for said duct mounted on bearings within the receptacle which permit of a free relative rotation of said receptacle and holder, and means for opposing the rotation of the said holder in the direction of the movement of the fluid while the receptacle is rotated, whereby the conducting fluid within the receptacle will be caused to flow through the duct against the conductors.

8. The combination with a receptacle and a motor for rotating the same, of a magnetic body mounted in the receptacle, a magnet exterior to the receptacle for maintaining the body stationary while the receptacle rotates, a series of conductors

in the receptacle and a duct carried by the said magnetic body and adapted to take up at one end a conducting fluid in the receptacle when the latter rotates and to direct such fluid from its opposite end against the series of conductors.

9. The combination with a receptacle for containing a conducting fluid, a series of spaced conductors within the same, and a motor, the armature of which is connected with the receptacle so as to impart rotation thereto, a magnetic body capable of turning freely within the receptacle about an axis concentric with that of the latter, a duct carried by the said body having one end in position to take up the conducting fluid and the other in position to discharge it against the spaced conductors, and a magnet exterior to the receptacle for holding the magnetic body stationary when the receptacle is rotated.

10. The combination with a closed receptacle in which is maintained an inert insulating gaseous medium under great pressure, of a circuit controller contained within the receptacle, as set forth.

11. The combination with a closed gas tight receptacle of a circuit controller contained within the same, and a vessel containing a liquefied gas, and communicating with the interior of the receptacle, as set forth.

12. The combination with a circuit controlling mechanism, one part or terminal of which is a conducting fluid, such as mercury, of a receptacle enclosing the same and means for maintaining an inert gas under pressure in the receptacle.

13. The combination with a conductor or series of conductors constituting one terminal of a circuit controller, means for maintaining a stream or jet of conducting fluid as the other terminal with which the conductor makes intermittent contact, a closed receptacle containing the terminals, and means for maintaining an inert atmosphere under pressure in the receptacle.

14. A device for making and breaking an electric circuit comprising, in combination, means for maintaining a jet or stream of conducting fluid which constitutes one terminal, a conductor or conductors making intermittent contact with the jet and constituting the other terminal and a receptacle enclosing and excluding oxygen from the said terminals.

15. The combination of a casing, a conductor or series of spaced conductors mounted therein, a motive device for rotating the said conductors, and a pumping device rigidly connected with the conductors for maintaining a stream or streams of conducting fluid directed against the rotating conductors, the said conductors and the fluid constituting respectively the terminals of a circuit controller.

16. The combination of a casing, a conductor or series of spaced conductors mounted therein, a motor for rotating the same, one or more ducts or channels from a receptacle containing a conducting fluid and directed towards the conductors, and a pump operated by the motor for forcing the conducting fluid through the duct or ducts against the conductors, the conductors and the fluid constituting the terminals of an electric circuit controller.

17. The combination with a receptacle containing a conducting fluid, of a conductor mounted within the receptacle, means for rotating the same, a screw rotating with the conductor and extending into a well in which the fluid collects, and a duct or ducts leading from the well to points from which the fluid will be directed against the rotating conductor.

18. The combination with the receptacle, of a spindle secured to its head or cover, a magnetic core mounted on the spindle within the receptacle, means for rotating said core, a conductor rotated by the core, and a pumping device, such as a screw rotated by the core and operating to maintain a jet or jets of conducting fluid, against the conductor, when in rotation.

19. The combination in a circuit controller with a closed receptacle, of a rigid body mounted within the receptacle and through which the circuit is intermittently established, and means for directing a jet or stream of a fluid contained in the receptacle against the said body so as to effect its rotation, as set forth.

20. The combination in a circuit controller of a jet of conducting fluid con-

stituting one terminal, a conductor adapted to be rotated by the force of the jet, and in its rotation to make intermittent contact therewith, and an enclosing receptacle, as set forth.

21. In an electric circuit controller, the combination of a closed receptacle, a conducting body therein adapted to be rotated by the impingement thereon of a jet or stream of conducting fluid, and means for maintaining such a jet and directing it upon the said conductor, as set forth.

22. In a circuit controller, the combination with a rotary receptacle of a body or part mounted within the receptacle and concentrically therewith, a conducting terminal supported by said body and capable of rotation in a plane at an angle to the plane of rotation of the receptacle so as to oppose, by gyrostatic action, the rotation of the support, and means for directing a jet of conducting fluid against the said terminal, as set forth.

23. In a circuit controller, the combination with a rotary receptacle of a support for a conductor mounted thereon concentrically with the receptacle and a gyrostatic disk carried by the support and adapted, when rotating, to oppose its movement in the direction of rotation of the receptacle, as set forth.

24. In a circuit controller, the combination with a rotary receptacle containing a conducting fluid, a support mounted within the receptacle, means for opposing or preventing its movement in the direction of rotation of the receptacle, one or more tubes or ducts carried thereby and adapted to take up the fluid from the rotating receptacle and discharge the same in jets or streams, and a conductor mounted on the support and adapted to be rotated by the impingement thereon of said jet or jets, as set forth.

25. The combination in a circuit controller of a rotary receptacle, one or more tubes or ducts and a support therefor capable of rotation independently of the receptacle, a conductor mounted on said support in a plane at an angle to that of rotation of the receptacle, and adapted to be maintained in rotation by a jet of fluid taken up from the receptacle by and discharged upon it from the said tube or duct, when the receptacle is rotated.

26. The combination with a rotary receptacle of one or more tubes or ducts, a holder or support therefor mounted on bearings within the receptacle, which permit of a free relative rotation of said receptacle and holder, a disk with a bearing on the said holder and having its plane of rotation at an angle to that of the receptacle, the disk being formed or provided with conducting vanes, upon which a jet of conducting fluid, taken up by the tube or duct from the receptacle when in rotation, is directed.

27. A circuit controller comprising in combination means for producing streams or jets of conducting liquid forming the terminals, and means for bringing the jets or streams of the respective terminals into intermittent contact with each other, as set forth.

28. In a circuit controller, the combination with two sets of orifices adapted to discharge jets in different directions, means for maintaining jets of conducting liquid through said orifices, and means for moving said orifices relatively to each other so that the jets from those of one set will intermittently intersect those from the other, as set forth.

29. The combination in a circuit controller of ducts and means for discharging therefrom streams or jets of conducting fluid in electrical contact with the two parts of the circuit respectively, the orifices of said ducts being capable of movement relatively to each other, whereby the streams discharged therefrom will intersect at intervals during their relative movement, and make and break the electric circuit, as set forth.

30. In a circuit controller the combination with one or more stationary nozzles and means for causing a conducting fluid forming one terminal to issue therefrom, of one or more rotating tubes or nozzles, means for causing a conducting liquid forming the other terminal to issue therefrom, the said rotating nozzles being

movable through such a path as to cause the liquid issuing therefrom to intersect that from the stationary nozzles as set forth.

31. The combination with a rotating receptacle divided into two insulated compartments, a spindle in one compartment with its axis concentric with that of the receptacle, means for opposing the rotation of said spindle, and a tube or duct carried by the spindle and adapted to take up a conducting fluid at one end from the inner periphery of the compartment when the receptacle is rotated and direct it from the other end into the other compartment, of a similar spindle in the other compartment and means for opposing its rotation, a tube carried by the spindle and having an opening at one end near the inner periphery of the compartment and discharging into a chamber from which lead one or more passages to nozzles fixed to the rotating receptacle and adapted to discharge across the path of the jet from the stationary nozzle, as set forth.

32. In a circuit controller the combination with a rotating receptacle of a body mounted thereon and formed or provided with a weighted portion eccentric to its axis which opposes its rotation and a tube or duct carried by said body and adapted to take up a conducting fluid from the rotating receptacle, as set forth.

33. In a circuit controller the combination of two sets of terminals symmetrically arranged about an axis of rotation and adapted to be brought successively into contact with each other, the number of terminals in one set being even and in the other odd, as set forth.

34. In a circuit controller the combination of two sets of terminals symmetrically arranged about an axis of rotation and adapted to be brought successively into contact with each other, there being one more terminal in one set than in the other, as set forth.

35. In a circuit controller the combination of two sets of nozzles and means for projecting from the same, jets of conducting fluid which constitute respectively the terminals of the controller, means for moving the nozzles relatively to each other so that the jets of the two sets are brought successively into contact, the nozzles of each set being arranged symmetrically about an axis of rotation, there being one more nozzle in one set than in the other.

36. In an electrical circuit controller, the combination with means for producing a stream or jet of conducting fluid which forms a path for the electric current of a body adapted to be intermittently moved through and to intercept the stream or jet, as set forth.

37. In an electrical circuit controller, the combination with a rigid terminal, of means for directing against such terminal a jet or stream of conducting fluid in electrical connection with the other terminal, and a body adapted to be intermittently moved through and to intercept the jet or stream, as set forth.

38. In an electrical circuit controller, the combination with a rigid terminal, of means for directing against such terminal a jet or stream of conducting fluid in electrical connection with the other terminal, a body having a series of radial projections and means for rotating the same so that the said projections will intermittently intercept the stream or jet, as set forth.

39. In a circuit controller, the combination with a rotary conductor forming one terminal, means for directing against such terminal a jet or stream of conducting fluid in electrical connection with the other terminal, and a body with spaced projections mounted to rotate in a path that intercepts the jet or stream of fluid, as set forth.

40. In a circuit controller, the combination with a conductor forming one terminal, and means for directing intermittently against such terminal a jet or stream of fluid in electrical connection with the other terminal, the part of said conductor upon which the jet or stream impinges being formed or arranged so as to retain, on its surface, a portion of the conducting fluid, as set forth.

41. The combination of the receptacle, a conducting disk secured within it, the insulated disk with peripheral projections and the stationary tube or duct for

directing a stream or jet of conducting fluid towards the conducting disk and across the path of the projections O, as set forth.

42. The combination of the receptacle, the conducting disk with a peripheral trough shaped flange, the insulated disk with peripheral projections O, and the stationary tube or duct for directing a stream or jet of conducting fluid into the trough shaped flange of the conducting disk and across the path of the projections O, as set forth.

43. A circuit controller comprising, in combination, a closed receptacle containing a fluid, means for rotating the receptacle, a support mounted within the receptacle, means for opposing or preventing its movement in the direction of rotation of the receptacle, and a conductor carried by said support and adapted to make and break electric connection with the receptacle through the fluid, as set forth.

44. A circuit controller comprising, in combination, a terminal capable of rotation and formed or provided with radiating contacts, a closed receptacle containing a fluid which constitutes the opposite terminal, means for rotating the receptacle, a support therein for the rotating terminal, and means for opposing or preventing the rotation of the support in the direction of the rotation of the receptacle, as set forth.

45. In a circuit controller, the combination with a receptacle capable of rotation about an axis inclined to the vertical and containing a fluid which constitutes one terminal, a second terminal mounted within the receptacle, on a support capable of free rotation relatively to the receptacle, and a weight eccentric to the axis of rotation of the support for said terminal for opposing or preventing its movement in the direction of the rotation of the said receptacle, as set forth.

46. The combination with a receptacle mounted to revolve about an axis inclined to the vertical, of a spindle within the receptacle and concentric with its axis, a weight eccentric to the spindle, and a terminal carried by the said spindle, and adapted to be rotated by a body of conducting fluid contained in the receptacle when the latter is rotated, as set forth.

47. The combination with a receptacle mounted to rotate about an axis inclined to the vertical, a spindle within the receptacle and concentric with its axis, a weighted arm attached to said spindle, a bracket or arm also secured to said spindle, a rotary terminal with radiating contact arms or vanes mounted on said bracket in position to be rotated by a body of conducting fluid contained in said receptacle when said fluid is displaced by centrifugal action, as set forth.

48. In a circuit controller, the combination with two terminals or sets of terminals, one of which is composed of a conducting fluid, of means for imparting to said terminals movements of rotation in opposite directions, as set forth.

49. The combination in a circuit controller of one or more bodies of conducting fluid and a conductor or conductors constituting, respectively, the terminals of said controller, and means for rotating said terminals in opposite directions, as set forth.

50. The combination in a circuit controller of a receptacle and means for rotating the same, one or more tubes or ducts mounted within the same and capable of rotation independently of the receptacle, means for imparting rotation to said ducts, and a conductor or series of conductors moving with the receptacle, in position to intermittently intercept jets of conducting fluid taken up by the ducts, as set forth.

51. In a circuit controller, the combination with a receptacle containing a conducting fluid, means for imparting a movement of rotation to the fluid, and a conductor adapted to be rotated by the movement of said fluid and to thereby make and break electric connection with the fluid, as set forth.

52. In a circuit controller, the combination with a terminal or series of terminals, contained in a receptacle, and a device operating by centrifugal action for taking

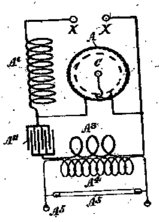


Fig. 1

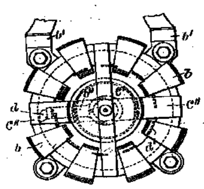


Fig. 2

Fig. 3

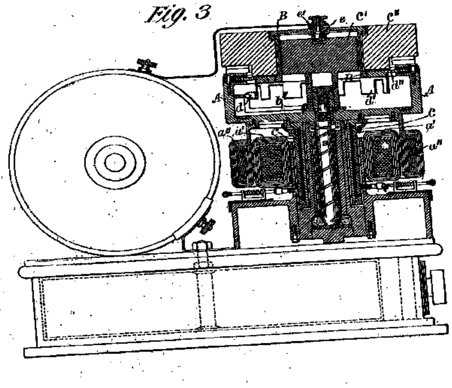


Fig. 4

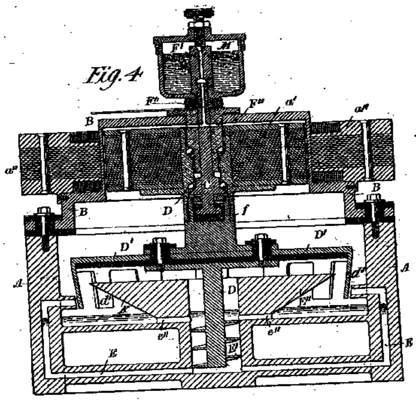
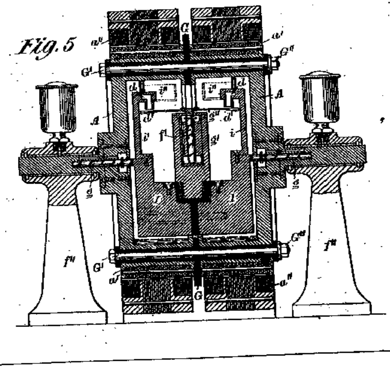


Fig. 5



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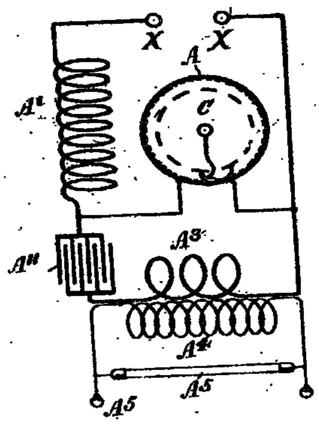


Fig. 1

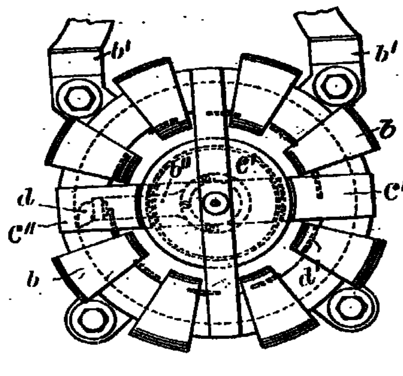


Fig. 2

Fig. 3

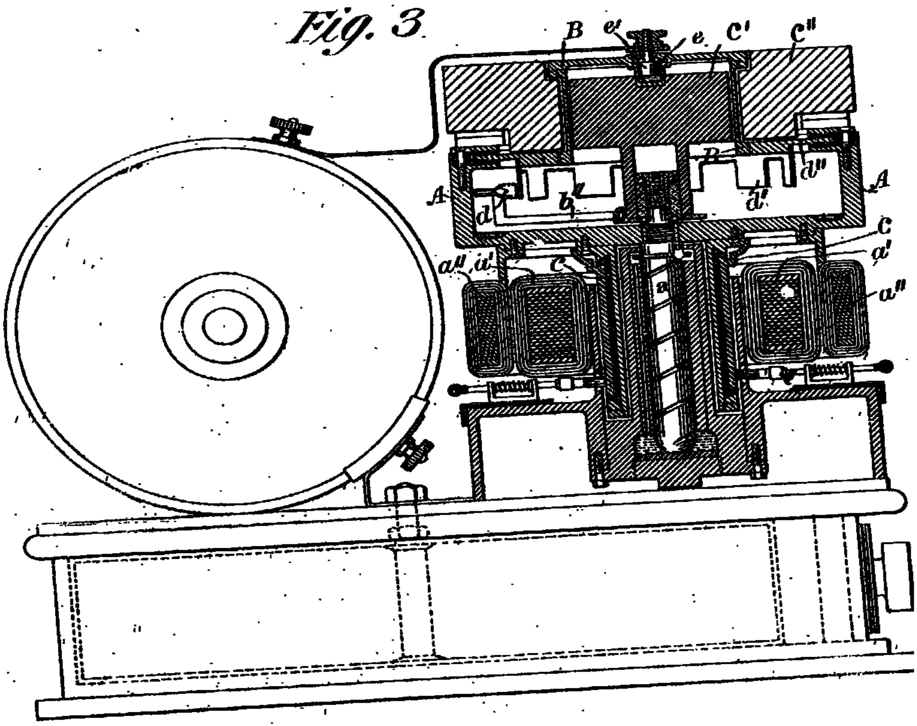


Fig. 4

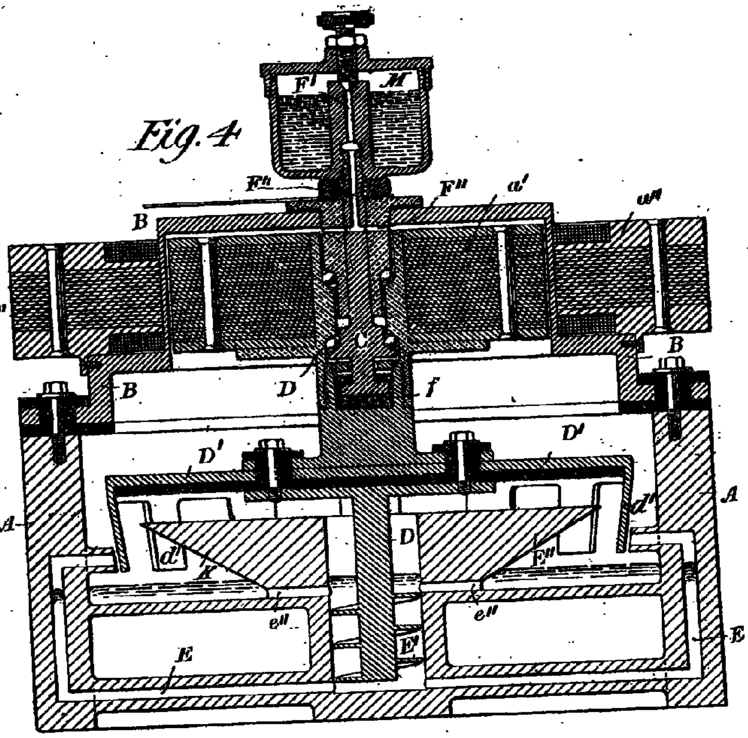
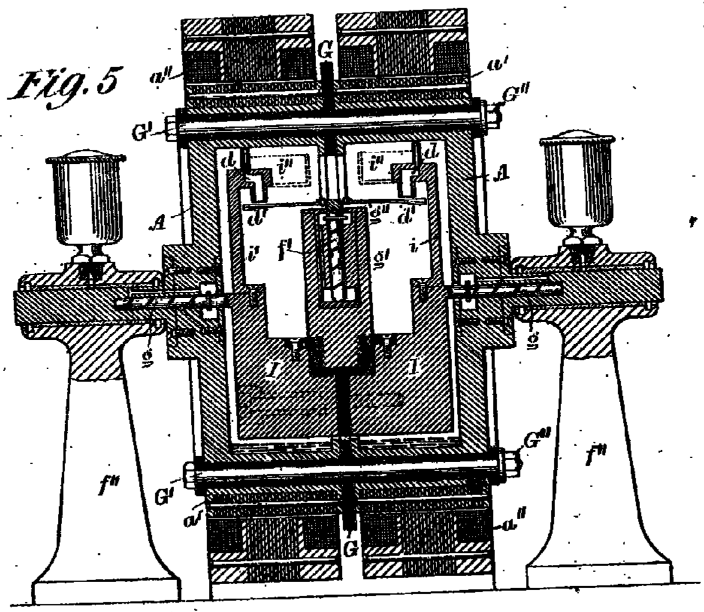


Fig. 5



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Malby & Sons, Photo-Litho.

Fig. 6

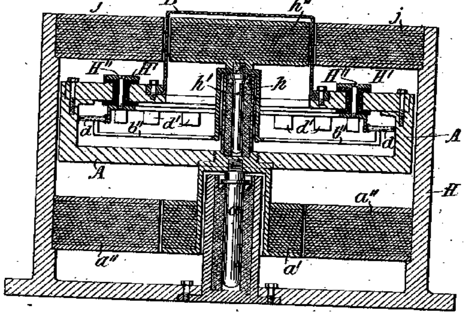

Fig. 7

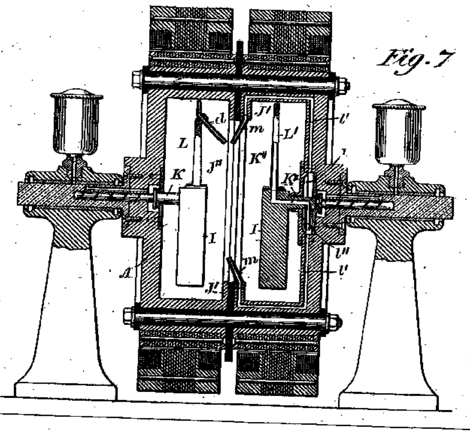

Fig. 8

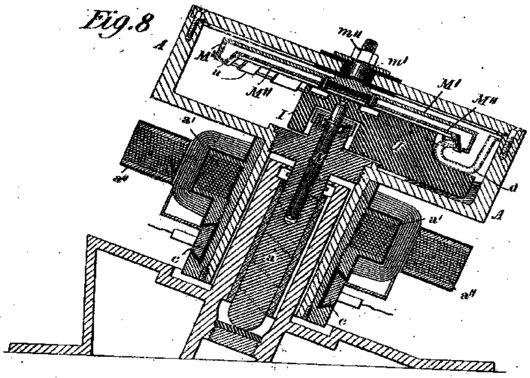

Fig. 11

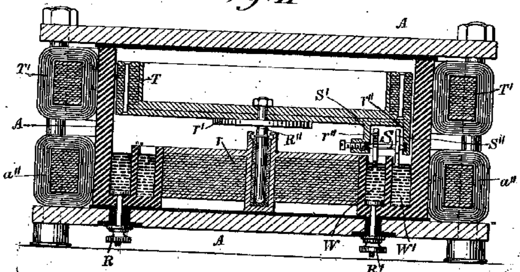

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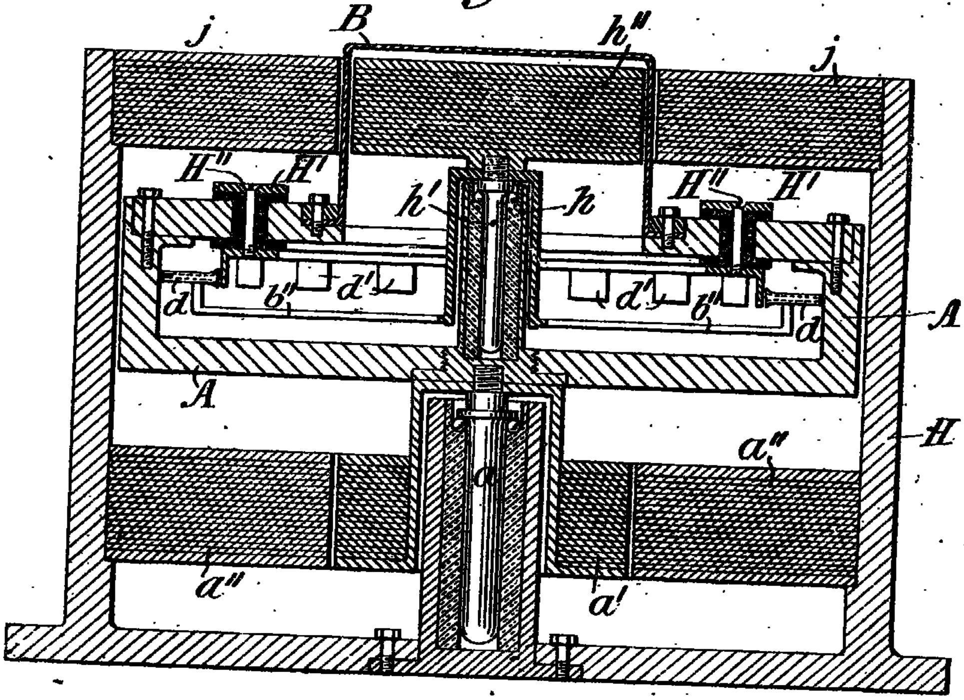
Fig. 6



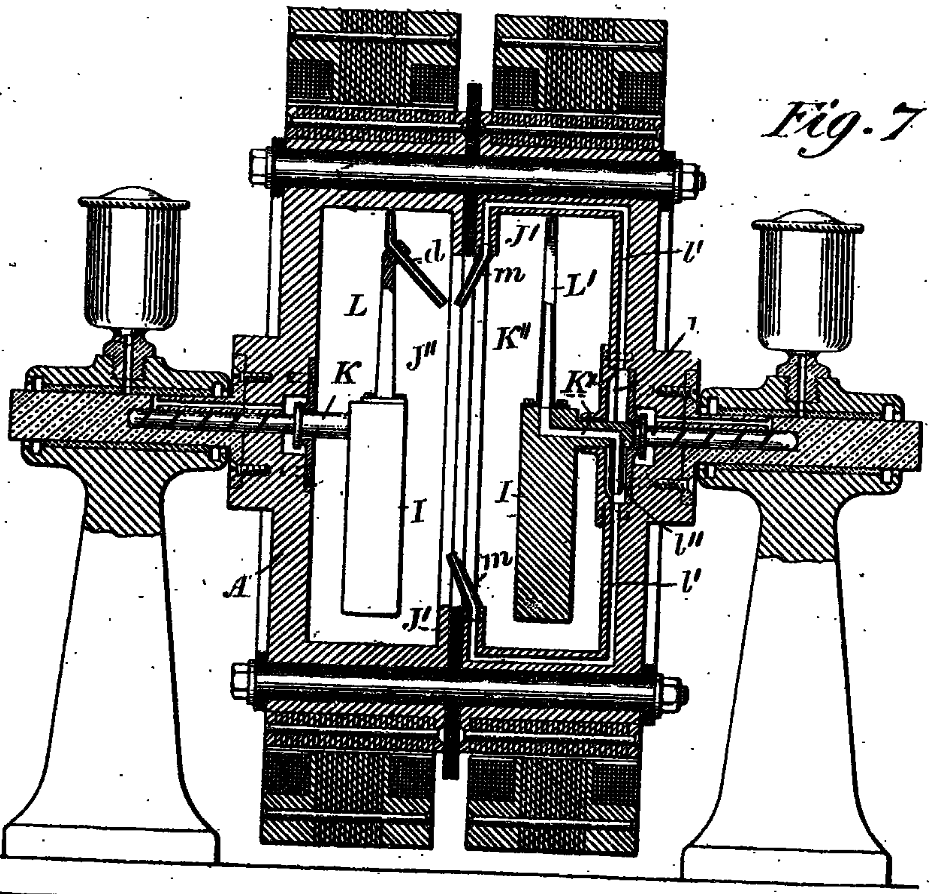


Fig. 7

Fig. 8

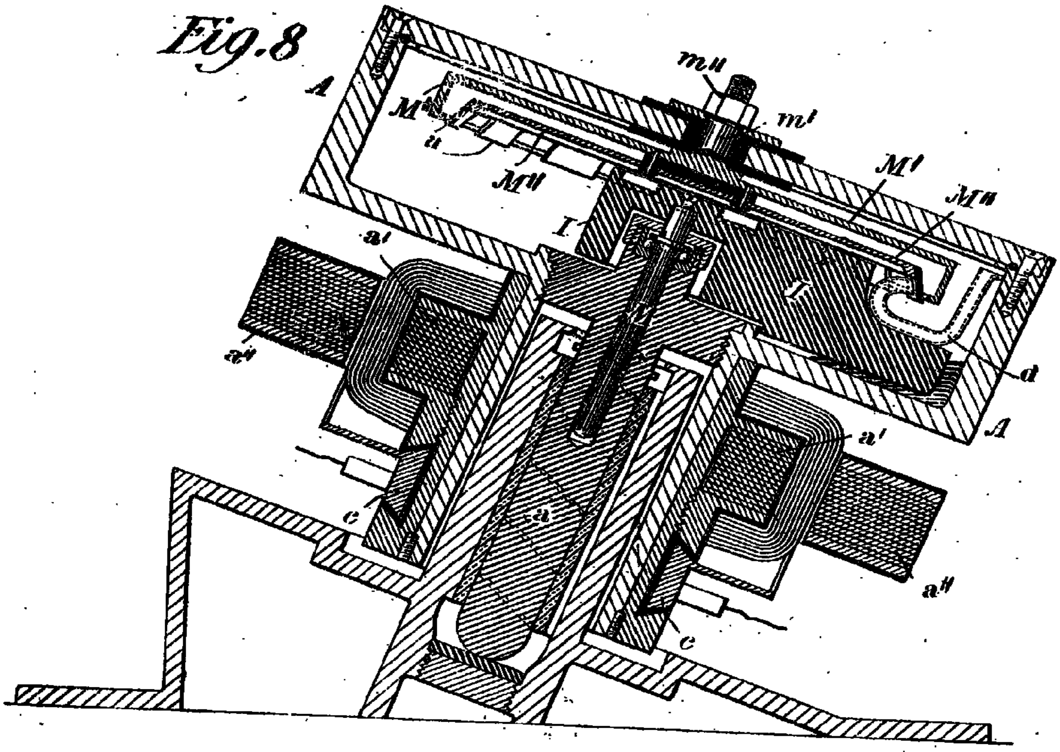


Fig. 11

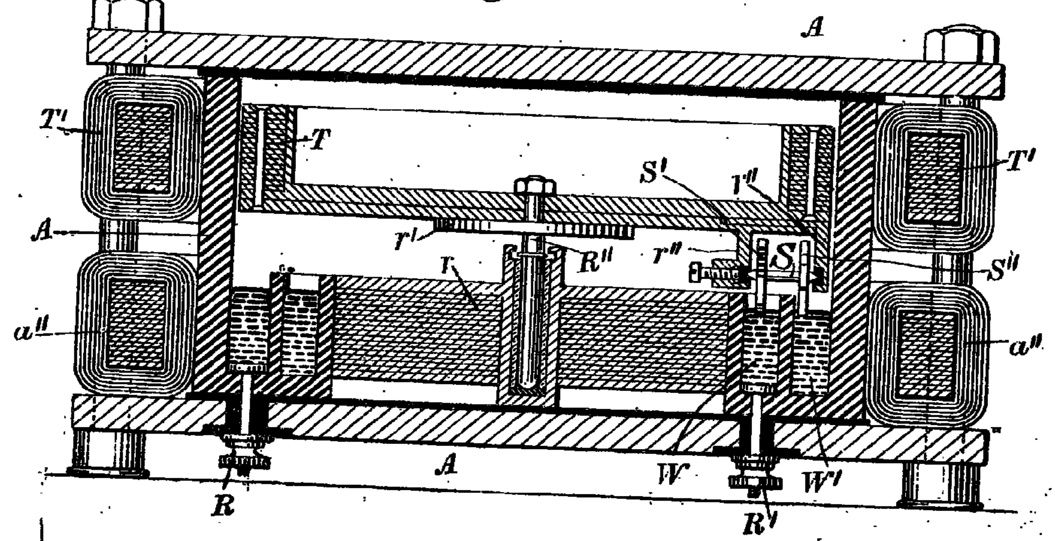


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Fig. 9

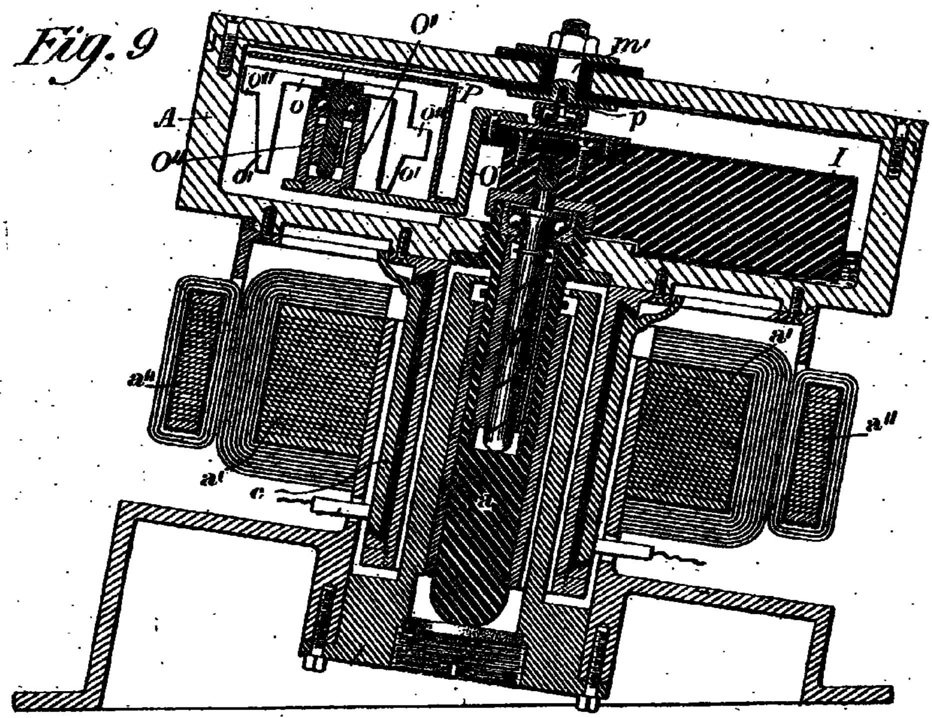
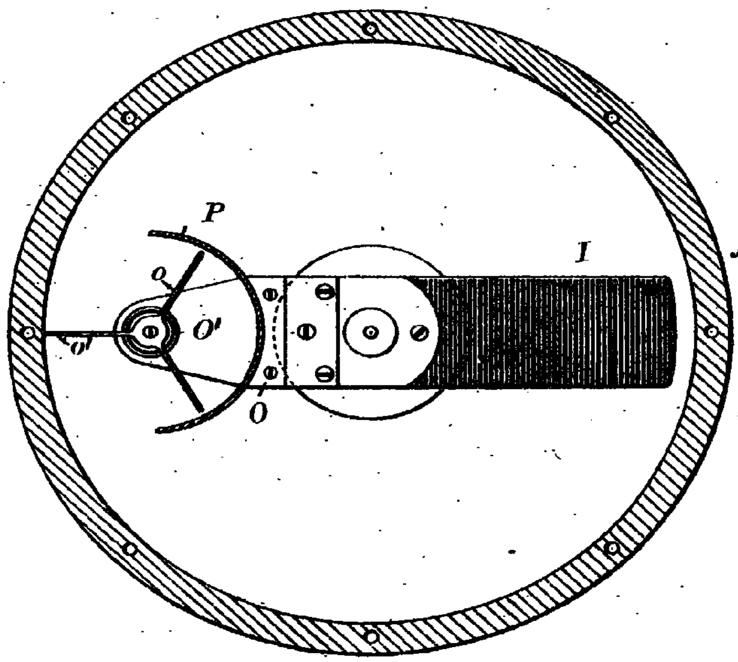


Fig. 10



[This Drawing is a reproduction of the Original on a reduced scale.]

N° 13,563 A.D. 1901

Date of Application, 3rd July, 1901—Accepted, 9th Nov., 1901

COMPLETE SPECIFICATION.

Communicated from abroad by Nikola Tesla of 46 East Houston Street City of New York State of New York United States of America, Electrician.

"Improvements in, and relating to, the Transmission of Electrical Energy."

I, Henry Harris Lake, of the Firm of Haseltine, Lake & Co., Patent Agents, 45 Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In many scientific and practical uses of electrical impulses or oscillations, as, for example, in systems of transmitting intelligence to distant points by signals conveyed through artificial channels or through the natural media, it is of great importance to intensify, as much as possible, the current impulses or vibrations, which are produced in the circuits of the transmitting and receiving instruments, particularly of the latter.

It is well known that when electrical impulses are impressed upon a circuit adapted to oscillate freely, the intensity of the oscillations developed in the same is dependent on the magnitude of its physical constants and the relation of the periods of the impressed and of the free oscillations. For the attainment of the best result it is necessary, that the period of the impressed should be the same as that of the free oscillations, under which conditions the intensity of the latter is greatest and chiefly dependent on the inductance and resistance of the circuit, being directly proportionate to the former and inversely to the latter. Evidently then, in order to intensify the impulses or oscillations excited in the circuit, in other words, to produce the greatest rise of current or electrical pressure in the same, it is desirable to make its inductance as large, and its resistance as small as practicable.

Having this end in view, I have devised and used conductors of special and advantageous forms and of relatively very large cross section; but I have found that limitations exist in regard to the increase of the inductance as well as to the diminution of the resistance. This will be understood when it is borne in mind, that the resonant rise of current or pressure in a freely oscillating circuit is proportionate to the frequency of the impulses, and that a large inductance in general involves a slow vibration. On the other hand, an increase of the section of the conductor, with the object of reducing its resistance, is, beyond a certain limit, of little or no value, principally because electrical oscillations, particularly those of high frequency, pass mainly through the superficial conducting layers, and while it is true that this drawback may be overcome in a measure by the employment of thin ribbons, tubes or stranded cables, yet in practice other disadvantages arise, which often more than offset the gain.

It is a well-established fact that, as the temperature of a metallic conductor rises, its electrical resistance increases, and in recognition of this, constructors of commercial electrical apparatus have since long ago resorted to many expedients for preventing the coils and other parts of the same from becoming heated when in use, but merely with a view to economizing energy and reducing the cost of construction and operation of the apparatus.

Now I have discovered, that when a circuit adapted to vibrate freely is maintained at a low temperature, the oscillations excited in the same are, to an extraordinary degree, magnified and prolonged, and I am thus enabled to produce many valuable results, which have heretofore been wholly impracticable.

Briefly stated, then, my invention consists in producing a great increase in the intensity and duration of the oscillations excited in a freely vibrating or resonating circuit, by maintaining the same at a low temperature.

Ordinarily, in commercial apparatus, such provision is made only with the object of preventing wasteful heating and, in any event, its influence upon the intensity of the oscillations is very slight and practically negligible, for as a rule, impulses of arbitrary frequency are impressed upon a circuit, irrespective of its own free vibrations, and a resonant rise is expressly avoided. My invention, it will be understood, does not, primarily, contemplate the saving of energy, but aims at the attainment of a distinctly novel and valuable result; that is, the increase, to the greatest practicable degree, of the intensity and duration of free oscillations. It may be usefully applied in all cases when this special object is sought, but offers exceptional advantages in those instances in which, the freely oscillating discharges of a condenser are utilized.

The best and most convenient manner of carrying out the invention of which I am now aware, is to surround the freely vibrating circuit or conductor, which is to be maintained at a low temperature, with a suitable cooling medium, which may be any kind of freezing mixture or agent, such as liquid air, and in order to derive the fullest benefit from the improvement, the circuit should be primarily constructed so as to have the greatest possible self-induction and the smallest practicable resistance, and other rules of construction, which are now recognized, should be observed. For example, when, in a system of transmission of energy for any purpose through the natural media, the transmitting and receiving conductors are connected to earth and to an insulated terminal respectively, the lengths of these conductors should be one quarter of the wave length of the disturbance propagated through them.

In the accompanying drawing I have shown graphically a disposition of apparatus, which may be used in applying practically my invention.

The drawing illustrates in perspective two devices, either of which may be the transmitter, while the other is the receiver. In each there is a coil of few turns and low resistance, designated in one by A, and in the other by A^1. The former coil, supposed to be forming part of the transmitter, is to be connected with a suitable source of current, while the latter is to be included in circuit with a receiving device.

In inductive relation to said coils in each instrument is a flat spirally wound coil B, or B^1, one terminal of which is shown as connected to a ground plate C, while the other, leading from the center, is adapted to be connected to an insulated terminal.

The coils B, B^1 are placed in insulating receptacles D, which contain the freezing agent and around which the coils A and A^1 are wound.

Coils in the form of a flat spiral, as those described, are eminently suited for the production of free oscillations, but obviously, conductors or circuits of any other form may be used, if desired.

From the foregoing the operation of the apparatus will now be readily understood. Assume first, as the simplest case, that upon the coil A of the transmitter impulses or oscillations of an arbitrary frequency and irrespective of its own free vibrations, are impressed. Corresponding oscillations will then be induced in the circuit B which, being constructed and adjusted as before indicated, so as to vibrate at the same rate, will greatly magnify them, the increase being directly proportionate to the product of the frequency of the oscillations and the inductance of circuit B, and inversely to the resistance of the latter. Other conditions remaining the same, the intensity of the oscillations in the resonating circuit B will be increased in the same proportion as its resistance is reduced. Very often, however, the conditions may be such that the gain sought is not realized directly by diminishing the resistance of the circuit. In such cases the skilled expert who applies my invention, will turn to advantage the reduction of resistance by using a correspondingly longer conductor, thus securing a much greater self-induction and, under all circumstances, he will determine the dimensions of the circuit so as to get the greatest value of the ratio of its inductance to its resistance, which determines the intensity of the free oscillations.

The vibrations of coil B, greatly strengthened, spread to a distance and on reaching through the ground or other conducting medium the tuned receiving conductor B^1, excite corresponding oscillations in the same, which, for similar reasons, are intensified, with the result of inducing correspondingly stronger currents or oscillations in circuit A^1, including the receiving device.

When, as may be the case in the transmission of intelligible signals, the circuit A is periodically closed and opened, the effect upon the receiver is heightened in the manner above described not only because the impulses in the coils B and B^1 are strengthened, but also on account of their persistance through a longer interval of time. The advantages offered by my invention are still more fully realized when the circuit A of the transmitter, instead of having impulses of an arbitrary frequency impressed upon it, is permitted to vibrate itself at its own rate, and more particularly so, if it be energized by the freely oscillating high frequency discharges of a condenser.

In such a case, the cooling of the conductor A, which may be effected in any suitable manner, results in an extraordinary magnification of the oscillation in the resonating circuit B, which I attribute to the increased intensity as well as greater number of the high frequency oscillations obtained in the circuit A. The receiving coil B^1 is energized stronger in proportion and induces currents of greater intensity in the circuit A^1. Evidently, if desired, the latter may be also tuned and kept at a low temperature with the object above set forth in view, and it will be clear, that the greater the number of the freely vibrating circuits which alternately receive and transmit energy from one to another, the greater, relatively, will be the gain secured by applying my invention.

I do not, of course, intend to limit myself to the specific manner and means described of artificial cooling, nor to the particular forms and arrangements of the circuits shown. By taking advantage of the facts above pointed out and of the means described, I have found it possible to secure a rise of electrical pressure in an excited circuit very many times greater than has heretofore been obtainable, and this result makes it practicable, among other things, to greatly extend the distance of transmission of signals and to exclude much more effectively interferences with the same than has been possible heretofore.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

1. The combination with a circuit adapted to vibrate freely, of means for artificially cooling the same to a low temperature, as herein set forth.

2. In an apparatus for transmitting or receiving electrical impulses or oscillations, a primary and a secondary circuit, one or both adapted to vibrate freely in response to the impressed oscillations, and means for artificially cooling the excited circuit or circuits to a low temperature, as herein set forth.

3. In a system for the transmission of electrical energy, a circuit upon which electrical oscillations are impressed, and which is adapted to vibrate freely, and a receptacle containing an artificial refrigerant in which said circuit is immersed, as herein set forth.

4. The means of increasing the intensity of the electrical impulses or oscillations impressed upon a freely vibrating circuit, consisting of an artificial refrigerant applied to such circuit and adapted to maintain the same at a low temperature.

5. The means of intensifying and prolonging the electrical oscillations pro-

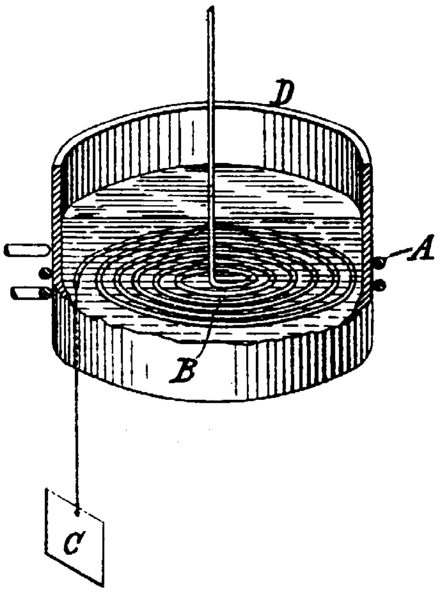
duced in a freely vibrating circuit, consisting of an artificial refrigerant applied to such circuit and adapted to maintain the same at a uniformly low temperature.

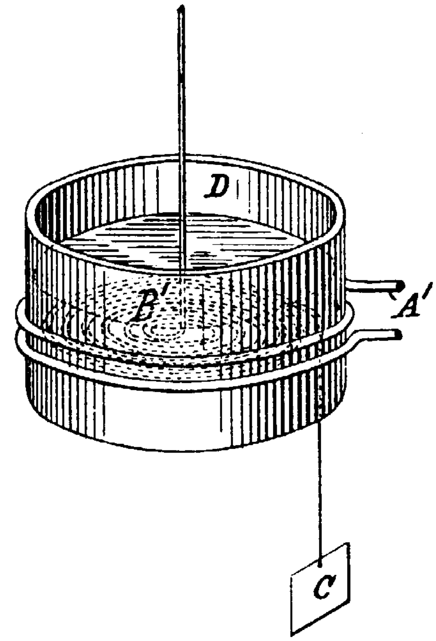
6. In a system for the transmission of energy, a series of transmitting and receiving circuits adapted to vibrate freely, and means for artificially maintaining the same at a low temperature, as set forth.

Dated this 3rd day of July 1901.

HASELTINE, LAKE & Co.,
45 Southampton Buildings, London, W.C.,
Agents for the Applicant.

Redhill: Printed for His Majesty's Stationery Office, by Malcomson & Co., Ltd.—1901.


D
A
B
C


D
B'
A'
C

N° 14,550 A.D. 1900

Date of Application, 14th Aug., 1900—Accepted, 12th Jan., 1901

COMPLETE SPECIFICATION.

Communicated from abroad by NIKOLA TESLA, of 46, East Houston Street, in the City and State of New York, United States of America, Electrician.

Improvements relating to the Insulation of Electric Conductors.

I, HENRY HARRIS LAKE, of the Firm of Haseltine, Lake & Co., Patent Agents, 45, Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

It has long been known that many substances, which are more or less conducting when in the fluid condition, become insulators when solidified. Thus water, which is, in a measure, conducting, acquires insulating properties when converted into ice. The existing information on this subject, however, has been heretofore of a general nature only, and chiefly derived from the original observations of Faraday, who estimated that the substances upon which he experimented, such as water and aqueous solutions, insulate an electrically charged conductor about one hundred times better when rendered solid by freezing, and no attempt has been made to improve the quality of the insulation obtained by this means, or to practically utilize it for such purposes as are contemplated in my present invention.

In the course of my own investigations, more especially those of the electric properties of ice, I have discovered some novel and important facts, of which the more prominent are the following: First, that under certain conditions, when the leakage of the electric charge, ordinarily taking place, is rigorously prevented, ice proves itself to be a much better insulator than has heretofore appeared; second, that its insulating properties may be still further improved by the addition of other bodies to the water; third, that the di-electric strength of ice or other frozen aqueous substance increases with the reduction of temperature and corresponding increase of hardness; and fourth, that these bodies afford a still more effective insulation for conductors carrying intermittent or alternating currents, particularly of high rates; surprisingly thin layers of ice being capable of withstanding electromotive forces of many hundreds, and even thousands of volts.

These and other observations have led me to the invention of a novel method of insulating conductors, rendered practicable by reason of the above facts, and advantageous in the utilization of electrical energy for industrial and commercial purposes. Broadly stated, the method consists in insulating an electric conductor by freezing or solidifying, and maintaining in such state, by the circulation of a gaseous cooling agent, the material surrounding or contiguous to the conductor.

In the practical carrying out of my method I may employ a hollow conductor and pass the cooling agent through the same, thus freezing the water or other medium in contact with or close to such conductor; or I may use, expressly for the circulation of the cooling agent, an independent channel and freeze or solidify the adjacent substance, in which any number of conductors may be imbedded.

The conductors may be bare or covered with some material which is capable of keeping them insulated when it is frozen or solidified. The frozen mass may be in direct touch with the surrounding medium, or it may be in a degree protected from contact with the same, by an enclosure more or less impervious to heat. The cooling agent may be any kind of gas, as atmospheric air, oxygen, carbonic acid, ammonia, illuminating gas or hydrogen. It may be forced through the channel by pressure or suction produced mechanically or otherwise. It may be continually renewed or indefinitely used, being driven back and forth or steadily circulated in closed paths, under any suitable conditions as regards pressure, density, temperature and velocity.

To conduce to a better understanding of the invention, reference is now made to the accompanying drawing, in which Figures 1, 3, 8 and 9, illustrate, in longitudinal section, typical ways of carrying out my invention, and Figures 2, 4, 5, 6, 7, and 10, in section or partly so, constructive details to be described.

In Figure 1, 2 is a hollow conductor, such as a steel tube, laid in a body of water and communicating with a reservoir 3, but electrically insulated from the same at 4. A pump or compressor 5 of any suitable construction connects 3 with another similar tank 6, provided with an inlet valve 7. The air or other gas which is used as the cooling agent, entering through the valve 7, is drawn through the tank 6 and pump 5 into the reservoir 3, escaping thence through the conductor 2 under any desired pressure which may be regulated by a valve 28. Both the reservoirs 3 and 6 are kept at a low temperature by suitable means, as by coils or tubes 9, 9 and 10, 10, through which any kind of refrigerating fluid may be circulated, some provision being preferably made for adjusting the flow of the same, as by valves 8.

The gas continuously passing through the tube or conductor 2, being very cold, will freeze and maintain in this state the water in contact with or adjacent to the conductor, and so insulate it. Flanged bushings 11, 12 of non-conducting material, may be used to prevent the leakage of the current, which would otherwise occur, owing to the formation of a superficial film of moisture over the ice projecting out of the water. The tube, being kept insulated by this means, may then be employed in the manner of an ordinary telegraphic or other cable by connecting either or both of the terminals 13, 14, in a circuit including the earth.

In many cases it will be of advantage to cover the hollow conductor with a thick layer of some cheap material, as felt, this being indicated by 15 in Figure 2. Such a covering, penetrable by water, would be ordinarily of little or no use, but when imbedded in the ice it improves the insulating qualities of the same. In this instance it furthermore serves to greatly reduce the quantity of ice required, its rate of melting, and the influx of heat from the outside; thus diminishing the expenditure of energy necessary for the maintenance of normal working conditions. As regards this energy and other particulars of importance, they will vary according to the special demands in each case.

Generally considered, the cooling agent will have to carry away heat at a rate sufficient to keep the conductor at the desired temperature and to maintain a layer of the required thickness of the substance surrounding it in a frozen state, compensating continually for the heat flowing in through the layer and wall of the conductor and that generated by mechanical and electrical friction. To meet these conditions its cooling capacity, which is dependent on the temperature, density, velocity and specific heat, will be calculated by the help of data and formulae familiar to engineers.

Air, as a rule, will be suitable for the use contemplated, but in exceptional instances some other gas, as hydrogen, may be resorted to, which will permit a much greater rate of cooling and a lower temperature to be reached. Obviously, whichever gas be employed, it should, before entering the hollow conductor or channel, be thoroughly dried and separated from all which, by condensation and deposition or otherwise, might cause an obstruction to its passage. For these purposes apparatus may be employed which is well-known and which it is unnecessary to show in detail.

Instead of being wasted at the distant station, the cooling agent may be turned to some profitable use. Evidently, in the industrial and commercial exploitation of my invention, any kind of gaseous cooling agent capable of meeting the requirements may be conveyed from one to another station and there utilized for refrigeration, power, heating, lighting, sanitation, chemical processes, or any other purpose to which it may lend itself, and thus the revenue of the plant may be increased.

As to the temperature of the conductor, it will be determined by the nature of its use and considerations of economy. For instance, if it be employed for the transmission of telegraphic messages, when the loss in electrical friction may be of no consequence, a very low temperature may not be required; but if it be used for transmitting large amounts of electrical energy, when the frictional waste may be a serious drawback, it will be desirable to keep it extremely cold. The attainment of this object will be facilitated by any provision for reducing as much as possible the flowing in of the heat from the surrounding medium. Clearly, the lower the temperature of the conductor the smaller will be the loss in electrical friction; but, on the other hand, the colder the conductor the greater will be the influx of heat from the outside, and the cost of the cooling agent. From such and similar considerations the temperature securing the highest economy will be ascertained.

Usually, in the distribution of electricity for industrial purposes, more than one conductor will be required, and in such cases it may be convenient to circulate the cooling agent in a closed path formed by the conductors. A plan of this kind is illustrated in Figure 3, in which 16 and 17 represent two hollow conductors imbedded in a frozen mass underground and communicating, respectively, with the reservoirs 18 and 19, which are connected by a reciprocating or other suitable pump 20. Cooling coils or tubes 21, 21, and 22, 22, with regulating valves 8, 8, are employed, which are similar to and serve the same purpose as those shown in Figure 1. Other features of similarity, though unnecessary, are illustrated to facilitate an understanding of the plan. A three-way valve 23 is provided which, when placed with its lever 24 as indicated, allows the cooling agent to enter through the tubes 25, 26 and pump 20, thus filling the reservoirs 18, 19 and hollow conductors 16, 17, but when turned ninety degrees, the valve shuts off the communication to the outside through the tube 25 and establishes a connection between the reservoir 19 and pump 20 through the tubes 26 and 27, thus permitting the fluid to be circulated in the closed path 16, 17, 19, 27, 26. 20, 18, by the action of the pump. Another valve 28 of suitable construction, may be used for regulating the flow of the cooling agent. The conductors 16, 17, are insulated from the reservoirs 18, 19, and from each other at the joints 29, 30, 31, and they are furthermore protected at the places where they enter and leave the ground, by flanged bushings 11, 11, 12, 12, of insulating material, which extend into the frozen mass in order to prevent the current from leaking, as above explained. Binding posts 32, 32, and 33, 33, are provided for connecting the conductors to the circuit at each station.

In laying the conductors, as 16, 17, whatever be their number, a trench will generally be dug, and a trough, round or square, as 34, of smaller dimensions than the trench, placed in the same, the intervening space being packed with some material, designated by 35, more or less impervious to heat, as sawdust, ashes or the like. Next the conductors will be put in position and temporarily supported in any convenient manner and, finally, the trough will be filled with water or other substance 36, which will be gradually frozen by circulating the cooling agent in the closed path, as before described. Usually the trench will not be level, but will follow the undulations of the ground, and this will make it necessary to subdivide the trough in sections, or to effect the freezing of the substance filling it, successively in parts. This being done and the conductors thus insulated and fixed, a layer of the same or similar material 35 will be placed on the top and the whole covered with earth or pavement. The trough may be of metal, as sheet iron, and in cases where the ground is used as return circuit, it may serve as a main; or it may be of any kind of material more or less insulating.

Figure 4 and Figure 5 illustrate, in cross section, two such underground troughs 34, of sheet metal with their adiathermanous inclosures designated 37 and 38, respectively, each trough containing a single central, hollow conductor, as 16 and 17. In the first case the insulation 36 is supposed to be ice, obtained by freezing water preferably freed of air, in order to exclude the formation of dangerous bubbles or cavities; while in the second case the frozen mass 39 is some aqueous or other substance or mixture, highly insulating when in this condition.

It should be stated that in many instances it may be practicable to dispense with a trough by resorting to similar expedients in the placing and insulating of the conductors. In fact, for some purposes it may be sufficient to simply cover the latter with a moist mass, as cement, or other plastic material which, so long as it is kept at a very low temperature and frozen hard, will afford adequate insulation.

Another typical way of carrying out my invention, to which reference has already been made, is shown in Figure 6, which represents the cross section of a trough the same in other respects as those before shown, but containing, instead of a hollow conductor, any kind of pipe or conduit 40. The cooling agent may be driven in any convenient manner through the pipe for the purpose of freezing the water or other substance filling the trough, thus insulating and fixing a number of conductors 41. Such a plan may be particularly suitable in cities for insulating and fixing telegraph and telephone wires, or the like. In such cases an exceedingly low temperature of the cooling agent may not be required, and the insulation will be obtained at the expense of little power. The conduit 40 may, however, be used simultaneously for conveying and distributing any kind of gaseous cooling agent for which there is a demand through the district. Obviously, two such conduits may be provided and used in a similar manner as the conductors 16, 17.

It will often be desirable to place in the same trough a great number of wires or conductors, serving for a variety of purposes. In such a case a plan may be adopted which is illustrated in Figure 7, showing a trough similar to that in Figure 6, with the conductors in cross section. The cooling agent may be in this instance circulated, as in Figure 3 or otherwise, through the two hollow conductors 42 and 42, which, if found advantageous, may be covered with a layer of cheap material 43, such as will improve their insulation, but not prevent the freezing or solidification of the surrounding substance 36. The tubular conductors 42, 42, preferably of iron, may then serve to convey heavy currents for supplying light and power, while the small ones 44 imbedded in the ice or frozen mass, may be used for any other purposes.

While my invention contemplates chiefly the insulation of conductors employed in the transmission of electrical energy to a distance, it may be, obviously, otherwise usefully applied. In some instances, for example, it may be desirable to insulate and support a conductor in places, as ordinarily done by means of glass or porcelain insulators. This may be effected in many ways, by conveying a cooling agent either through the conductor or through an independent channel, and freezing or solidifying any kind of substance, thus enabling it to serve the purpose. Such an artificial insulating support is illustrated in Figure 8, in which 34 represents a vessel filled with water or other substance 36, frozen by the agent circulating through the hollow conductor 45, which is thus insulated and supported. To improve the insulation on the top, where it is most liable to give way, a layer of some substance 46, as oil, may be used, and the conductor may be covered near the support with insulation 47, as shown, the same extending into the oil for reasons well understood.

Another typical application of my invention is shown in Figure 9, in which 48 and 49 represent, respectively, the primary and secondary conductors, bare or insulated, of a transformer, which are wound on a core, 50, and immersed in water or other substance 36, contained in a jar 51, and, as before stated, preferably freed of air by boiling or otherwise. The cooling agent is circulated in any convenient manner, as through the hollow primary 48, for the purpose of freezing the substance 36. Flanged bushings 52, and oil cups 53, extending into the frozen mass, illustrate suitable means for insulating the ends of the two conductors and preventing the leakage of the currents. A transformer as described is especially fitted for use with currents of high frequency, when a low temperature of the conductors is particularly desirable, and ice affords an exceptionally effective insulation.

It will be understood that my invention may be applied in many other ways, that the special means here described will be greatly varied according to the necessities, and that in each case many expedients will be adopted, which are well known to engineers and electricians, and on which it is unnecessary to dwell. However, it may be useful to state, that in some instances a special provision will have to be made for effecting a uniform cooling of the substance surrounding the conductor throughout its length. Assuming, in Figure 1, the cooling agent to escape, at the distant end, freely into the atmosphere or into a reservoir maintained at low pressure, it will, in passing through the hollow conductor, move with a velocity steadily increasing towards the end, expanding isothermally or nearly so, and hence it will cause an approximately uniform formation of ice along the conductor. In the plan illustrated in Figure 3 a similar result will be, in a measure attained, owing to the compensating effect of the hollow conductors 16 and 17, which may be still further enhanced by reversing periodically the direction of the flow in any convenient manner. But in many cases special arrangements will have to be employed to render the cooling more or less uniform. For instance, instead of a single channel, as shown in Figures 4, 5, and 6, two concentric channels, 54 and 55, may be provided, and the cooling agent passed through one and returned through the other, as indicated diagrammatically in Figure 10. In this and any similar arrangement, when the flow takes place in opposite directions, the object aimed at will be more completely attained by reducing the temperature of the circulating cooling agent at the distant station, which may be done by simply expanding it into a large reservoir, as 56, or cooling it by means of a tube or coil 57, or otherwise. Evidently in the case illustrated, the concentric tubes may be used as independent conductors, insulated from each other by the intervening fluid, and from the ground by the frozen or solidified substance.

Generally, in the transmission of electrical energy in large amounts, when the quantity of heat to be carried off may be considerable, refrigerating apparatus, thoroughly protected against the inflow of heat from the outside, as usual, will be employed at both the stations, and, when the distance between them is very great, also at intermediate points, the machinery being advantageously operated by the currents transmitted or cooling agent conveyed. In such cases a fairly uniform freezing of the insulating substance will be attained without difficulty by the compensating effect of the oppositely circulating cooling agents. In large plants of this kind, when the saving of electrical energy in the transmission is the most important consideration, or when the chief object is to reduce the cost of the mains by the employment of cheap metal, as iron, or otherwise, every effort will be made to maintain the conductors at the lowest possible temperature, and well-known refrigerating processes, as those based on the regenerative principle, may be resorted to, and, in this and any other case, the hollow conductors or channels, instead of merely serving the purpose of conveying the cooling agent, may themselves form active parts of the refrigerating apparatus.

From the above description it will be readily seen that my invention forms a fundamental departure, in principle, from the established methods of insulating conductors employed in the industrial and commercial application of electricity. It aims broadly at obtaining insulation by the continuous expenditure of a moderate amount of energy, instead of securing it only by virtue of an inherent physical property of the material used as heretofore. More especially its object is to provide, when and wherever required, insulation of high quality, of any desired thickness and exceptionally cheap, and to enable the transmission of electrical energy under conditions of economy heretofore unattainable, and at distances until now impracticable, by dispensing with the necessity of using costly conductors and insulators.

Having now particularly described and ascertained the nature of the said invention, and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

1. The method of insulating electric conductors herein described which consists in imparting insulated properties to a material surrounding or contiguous to the said conductor by the continued action thereon of a gaseous cooling agent, as set forth.

2. The method of insulating electric conductors herein described which consists in reducing to and maintaining in a frozen or solidified condition the material surrounding or contiguous to the said conductor by the action thereon of a gaseous cooling agent maintained in circulation through one or more channels as set forth.

3. The method of insulating electric conductors herein described which consists in surrounding or supporting the conductor by material which acquires insulating properties when in a frozen or solidified state, and maintaining the material in such a state by the circulation through one or more channels extending through it of a gaseous cooling agent, as set forth.

4. The method of insulating an electric conductor which consists in surrounding or supporting said conductor by a material which acquires insulating properties when frozen or solidified, and maintaining the material in such state by passing a gaseous cooling agent continuously through a channel in said conductor, as set forth.

5. The method of insulating electric conductors, which consists in surrounding or supporting the said conductors by a material which acquires insulating properties when in a frozen or solidified state, and maintaining the material in such state by the continued application thereto of a gaseous cooling agent, as set forth.

6. The method of insulating electric conductors herein set forth which consists in surrounding or supporting the conductors by a material which acquires insulating properties when in a frozen or solidified state, and maintaining the material in such state by the circulation of a gaseous cooling agent through a circuit of pipes or tubes extending through the said material, as set forth.

7. The method of insulating electric conductors which consists in laying or supporting the conductors in a trough or conduit, filling the trough with a material which acquires insulating properties when frozen or solidified, and then causing a gaseous cooling agent to circulate through one or more channels extending through the material in the trough so as to freeze or solidify the material, as set forth.

Dated this 14th day of August 1900.

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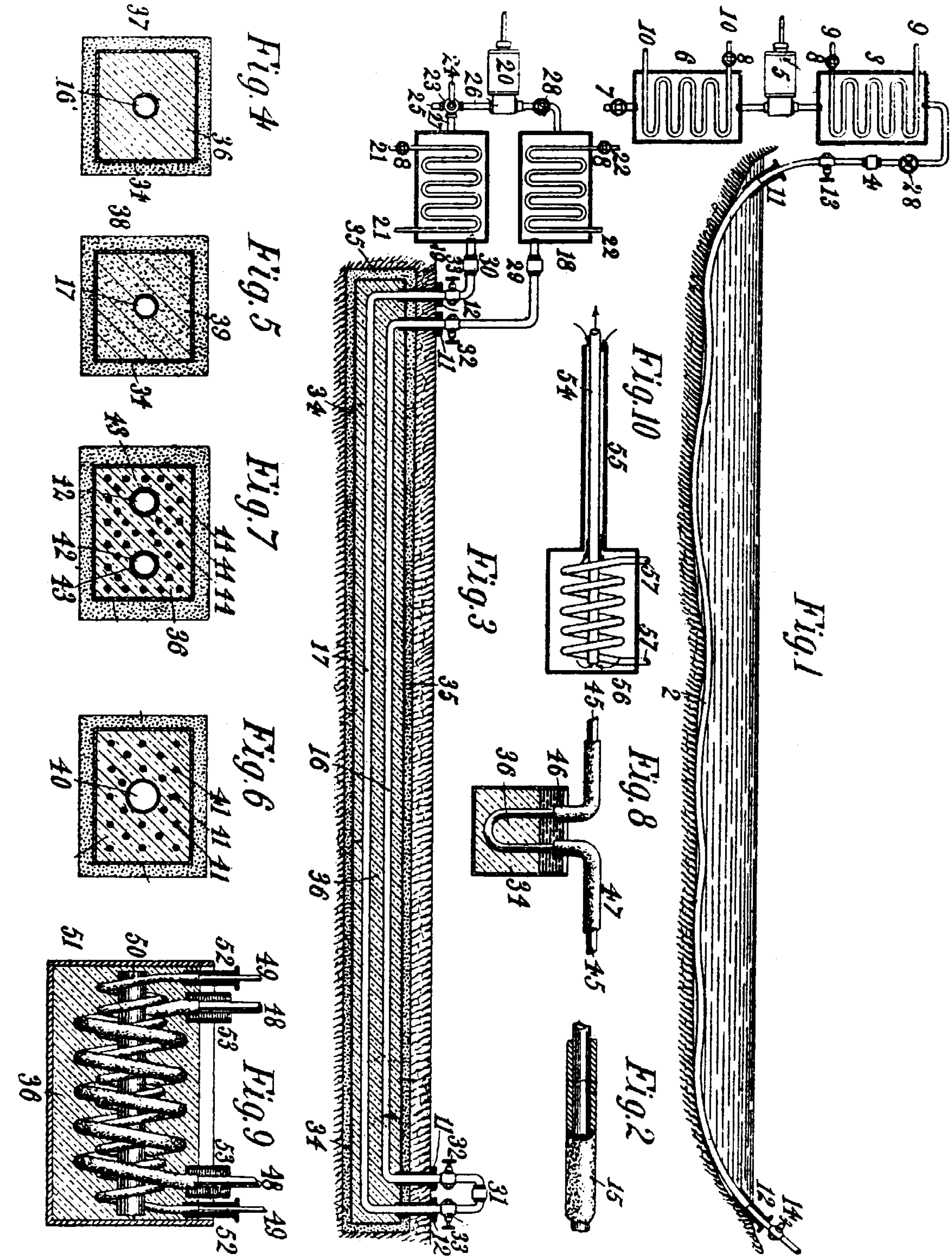
Fig.1
Fig.2
Fig.3
Fig.4
Fig.5
Fig.6
Fig.7
Fig.8
Fig.9
Fig.10

N° 14,579 A.D. 1901

Date of Application, 17th July, 1901—Accepted, 24th Apr., 1902

COMPLETE SPECIFICATION.

Communicated from abroad by Nikola Tesla, of 46 East Houston Street, Borough of Manhattan, City, County and State of New York, United States of America, Electrician.

"Improvements in and relating to the Transmission of Electrical Energy".

I, Henry Harris Lake, of the Firm of Haseltine, Lake & Co., Patent Agents, 45 Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In certain systems for transmitting intelligible messages, or governing the movements and operations of distant automata, electrical impulses or disturbances, produced by suitable apparatus, are conveyed through the natural media to a receiving circuit, capable of responding to the impulses and thereby effecting the control of other appliances. Generally a special device, highly sensitive, is connected to the receiving circuit which, in order to render it still more susceptible and to reduce the liability of its being affected by extraneous disturbances, is carefully synchronized with the transmitter. By a scientific design of the sending and receiving circuits and other apparatus, and skillful adjustment of the same, these objects may be in a measure attained, but notwithstanding all constructive advantages and experimental resources, this method is in many cases inadequate. Thus, while it is practicable to operate, selectively, under certain favorable conditions, more than one hundred receivers, in most cases it is possible to work successfully but a few, the number rapidly diminishing as, either owing to great distance or other causes, the energy available in the synchronized circuits becomes smaller, and therefore the receivers necessarily more delicate. Evidently a circuit, however excellently constructed and adjusted to respond exclusively to vibrations of one period, is apt to be affected by higher harmonics, and still more so by fundamental tones. When the oscillations are of a very high frequency, the number of the effective harmonics may be large, and the receiver is consequently easily disturbed by extraneous influences, to such an extent that, when very short waves, as those produced by Hertzian spark apparatus, are employed, little benefit in this respect is derived from synchronizing the circuits. It being an imperative requirement in most practical applications of such systems of signalling or intelligence transmission, that the signals or messages should be exclusive or private, it is highly desirable to do away with the above limitations, all the more so, as it is a fact, that the influence of powerful electrical disturbances upon sensitive receivers extends, even on land, to distances of many hundreds of miles and consequently, in accordance with theory, still farther on sea.

To overcome these drawbacks and to enable a great number of transmitting and receiving stations to be operated, selectively and exclusively, and without any danger of the signals or messages being disturbed or intercepted, or interfered with in any way, is the object of my present improvement.

Broadly stated, my invention involves the employment of means for generating two or more kinds or classes of disturbances, waves or impulses of distinctive character, with respect to their effect upon a receiving apparatus, and a distant receiver, which comprises two or more elements, severally responsive to the different disturbances or impulses, and which is dependent for operation upon the conjoint or resultant action of two or more such elements.

By employing only two kinds of disturbances or impulses instead of one, as has heretofore been done, to operate a receiver, safety against the disturbing influences of other sources is increased to such an extent, that this number is probably amply sufficient in most cases for rendering the exchange of signals or messages reliable and exclusive, but in exceptional instances a greater number may be used, and a degree of safety against mutual and extraneous interference attained, such as is comparable to that afforded by a combination lock. The liability of a receiver being affected by disturbances emanating from other sources, as well as that of the signals or messages being received by instruments for which they are not intended may, however, be reduced not only by an increased number of the co-operative disturbances or series of impulses, but also by a judicious choice of the same, order and mode in which they are made to act upon the receiver.

Evidently there are a great many ways of generating impulses or disturbances of any wave-length, wave-form, number or order of succession, or of any desired special character, such as will be capable of fulfilling the requirements above stated, and there are also many ways in which such impulses or disturbances may be made to co-operate and to cause the receiver to be actuated and, inasmuch as the skill and practical knowledge in these novel fields can only be acquired by long experience, the degree of safety and perfection attained will necessarily depend on the ability and resource of the expert who applies my invention, but in order to enable the same to be successfully practised by any person possessed only of the more general knowledge and experience in these branches, I shall describe the simplest plan of carrying it out, which is at present known to me.

For a better understanding of the subject, reference is now made to the drawing, in which.

Fig. 1 and Fig. 2 represent diagrammatically the apparatus and circuit connections at the sending and receiving stations, respectively, and

Figs. 3, 4 and 5 modified means which may be employed in the practical application of my invention.

In Fig. 1 S^1 and S^2 are two spirally wound coils or conductors, connected with their inner ends to preferably elevated terminals D^1 and D^2 respectively, and with their outer ends to an earth plate E. These two coils, conductors or systems D^1 S^1 E and D^2 S^2 E have different and suitably chosen periods of vibration and, their lengths should be such that the points of maximum pressure developed therein coincide with the elevated terminals D^1 D^2. By suitably chosen periods of vibration such periods are meant as will secure the greatest safety against interference, both mutual and extraneous. The most satisfactory results in this respect, are obtained when the different periods are related as the reciprocals of the smallest relative prime numbers, but whether this relation be observed or not, the vibrations should be so selected as to give, when passing through or acting upon a common path or circuit, the greatest practicable number of beats in the same. They should furthermore, as regards pitch, not approach too closely those of the order of the Hertzian, because with vibrations of such transcending rates, owing to the rapid radiation of energy into space, resonating systems, as D^1 S^1 E and D^2 S^2 E will not prove efficient intensifiers. The two systems may have electrical oscillations impressed upon them in any desired manner, conveniently by energizing them through primaries P^1 and P^2, placed in proximity to them. Adjustable inductances L^1 and L^2 are preferably included in the primary circuits chiefly for the purpose of regulating the rate of the primary oscillations. In the drawing these primaries P^1 and P^2 surround the coils S^1 S^2, and are joined in series through inductances L^1 L^2, conductor F, condensers C^1 and C^2, brush-holders B^1 and B^2 and a toothed disk D, which is connected to the conductor F and, if desired, also to the groundplate E, as shown, two independent primary circuits being thus formed. The condensers C^1 and C^2 are of such capacity and the inductances L^1 and L^2 are so adjusted that each primary is in close resonance with its secondary system. Care should be taken to obtain in each of the secondary systems D^1 S^1 E and D^2 S^2 E the true or fundamental note, as otherwise the apparatus may not perform satisfactorily. Assuming the capacities of the conductors S^1 and S^2 relatively small, the true notes will result when the product of capacity and inductance in each of the primaries is approximately equal to four times this product in each of the secondaries. The brush-holders B^1 and B^2 are capable, independently of angular and, if necessary, also of lateral adjustment, so that any desired order of succession or any difference of phase may be obtained between the discharges occurring in the two primary circuits. The condensers being energized from a suitable source S, preferably of high potential, and the disk D being rotated, its projections or teeth *p p*, coming at periodically recurring intervals in very close proximity to or, as the case may be, in contact with conducting rods or brushes *n n*, cause the condensers to be discharged in rapid succession through their respective circuits. In this manner the two secondary systems, D^1 S^1 E and D^2 S^2 E, are set in vibration and oscillate freely, each at its proper rate for a certain interval of time at every discharge. The two vibrations are impressed upon the ground through the plate E, and spread to a distance, reaching the receiving station, which has two similar circuits or systems e s^1 d^1 and e s^2 d^2, arranged and connected in the same manner and synchronized with the systems at the sending station, so as to respond each exclusively to one of the two vibrations of one kind or class produced by the transmitting apparatus. The same rules of adjustment are observed in the receiving circuits, care being furthermore taken that the synchronizing be effected when all the apparatus is connected to the circuits and placed in position, as any change may more or less modify the vibration. Each of the receiving coils s^1 and s^2 is shunted by a local circuit containing, respectively, sensitive devices a^1 a^2, batteries b^1 b^2, adjustable resistances r^1 r^2, and sensitive relays R^1 R^2, all joined in series as shown. The precise connections and arrangements of the various instruments are largely immaterial, and may be varied in a great many ways. The sensitive devices a^1 and a^2 may be any of the well-known devices, as for example, two conducting terminals separated by a minute air-gap or thin film of dielectric, which is strained or weakened by a battery or other means to the point of breaking down, and gives way to the slightest disturbing influence. Its return to the normal sensitive state may be secured by momentarily interrupting the battery circuit after each operation, or otherwise. The relays R^1 R^2 have armatures l^1 l^2, which are connected by a wire *w*, and when attracted, establish electrical contacts at c^1 and c^2, thus closing a circuit containing a battery b^3, an adjustable resistance r^3 and a relay R^3. From the above description it will be readily seen that the relay R^3 will be operated only when both contacts c^1 and c^2 are closed.

The apparatus at the sending station may be controlled in any suitable manner, as, for instance, by momentarily closing the circuit of the source S, two different electrical vibrations being emitted simultaneously or in rapid succession, as may be desired, at each closure of the circuit. The two receiving circuits at the distant station, each responding to the vibration produced by one of the elements of the transmitter, affect the sensitive devices a^1 and a^2 and cause the relays R^1 and R^2 to be operated and contacts c^1 and c^2 closed, thus actuating the receiver or relay R^3, which in turn establishes a contact c^3 and brings into action a device a^3 by means of a battery b^4 included in a local circuit, as shown. But evidently, if through any extraneous disturbance only one of the circuits at the receiving station is affected, the relay R^3 will fail to respond. In this way communication may be carried on with much increased safety against interference, and privacy of messages may be secured. The receiving station shown in Fig. 2 is supposed to be one requiring no return message, but if the use of the system is such that this is necessary, then the two stations may be equipped similarly, and any well-known means, which it is not thought necessary to illustrate here, may be resorted to for enabling the apparatus at each station to be used in turn as transmitter and receiver.

The terminals D^1 D^2 of the transmitting, and d^1 d^2 of the receiving apparatus are shown insulated from each other, but this, while advantageous, is not absolutely necessary, and each pair may be connected together, or else a single terminal, as D^1 or d^1, may be used at either of the stations, instead of two, as illustrated.

In like manner the operation of a receiver, as R^3, may be made dependent, instead of upon two, upon more than two such transmitting circuits or systems, and in this way any desired degree of exclusiveness or privacy and safety against extraneous disturbances may be attained. The apparatus, as illustrated in Fig. 1 and Fig. 2 permits, however, specific results to be secured by the adjustment of the order of succession or phase difference between the discharges of the primary circuits P^1 and P^2. To illustrate, the action of the relays R^1 R^2 may be regulated either by adjusting the weights of the levers l^1 r^2, or the strength of the batteries b^1 b^2, or the resistances r^1 r^2, or otherwise, so that, when a certain order of succession or difference of phase between the discharges of the primary circuits P^1 and P^2 exists at the sending station, the levers l^1 and l^2 will close the contacts c^1 c^2 at the same instant, and thus operate the relay R^3, but will fail to produce this result when the order of succession or difference of phase is another one. By these or similar means additional safety against disturbances from other sources may be obtained and, on the other hand, the possibility afforded of effecting the operation of signalling by varying the order of succession of the discharges in the two circuits. Instead of closing and opening the circuit of the source S, as before indicated, for the purpose of sending distinct signals, it may be convenient to merely alter the period of either of the transmitting circuits arbitrarily in any of the well-known ways, as by varying the inductance of the primaries. It should be stated, furthermore, in regard to the apparatus illustrated in Fig. 2, that special and useful results are obtainable by connecting contacts c^1 and c^2 in multiple arc instead of in series, as shown, in which case the relay R^3 will be necessarily either provided with two windings each controlled by one of the contacts, or otherwise constructed or adjusted so that it will not operate unless both of the contacts are closed.

Obviously there is no necessity for using transmitters with two or more distinct elements or circuits, as S^1 and S^2, since a succession of waves or impulses of different characteristics may be produced by an instrument having but one such circuit. A few of the many ways which will readily suggest themselves to the expert who applies my invention, are illustrated in Figs. 3, 4 and 5. In Fig. 3 a transmitting system e s^3 d^3 is partly shunted by a rotating wheel or disk D^3, which may be similar to that illustrated in Fig. 1, and which cuts out periodically a portion of the coil or conductor s^3, or, if desired, bridges it by an adjustable condenser C^3, thus altering the vibration of the system e s^3 d^3 at suitable intervals and causing two distinct kinds or classes of impulses to be emitted in rapid succession by the sender. In Fig. 4 a similar result is produced in the system e s^4 d^4 by periodically short-circuiting a secondary p^4, through an induction coil L^3 and a rotating disk D^4 with insulating and conducting segments, or otherwise. Again, in Fig. 5 three distinct vibrations are caused to be emitted by a system e s^5 d^5, the result being produced by inserting periodically a suitable number of turns of an induction coil L^4 in series with the oscillating system by means of a tating disk D^5 with two projections p^5 p^5, and three rods or brushes n^5, placed at an angle of one hundred and twenty degrees relative to each other. The three transmitting systems or circuits last described may be energized as those in Fig. 1 or in any other convenient way. Corresponding to each of these cases, the receiving station may be provided with two or three circuits, in an analogous manner to that illustrated in Fig. 2, it being understood, of course, that the different vibrations or disturbances emitted by the sender follow in such rapid succession upon each other that they are practically simultaneous, as far as the operation of the relays, such as R^1 and R^2 is concerned. Evidently, however, it is not necessary to employ two or more receiving circuits as s^1 and s^2, but single circuits may be used also at the receiving stations, constructed and arranged like the transmitting circuits or systems illustrated in Figs. 3, 4 and 5, in which case the corresponding disks, as D^3, D^4, D^5 at the sending will be driven in synchronism with those at the receiving stations, though this will not always be necessary.

The disks or other circuit controlling devices, operating synchronously at both the stations, may be constructed so as to enable the transmission of the impulses in any desired fixed or varying order of succession; and it is to be remarked that they will afford additional safety against interference in this instance, while they might prove ineffective in ordinary systems in which but one kind of disturbance is employed to operate a receiver.

To illustrate other useful features, reference may be again made to Figs. 1 and 2. I have found no difficulty in modifying the transmitting apparatus shown in Fig. 1 in such a way, that it will emit, instead of two, four vibrations of different periods. I accomplish this result by properly adjusting the inductances and capacities and the mutual induction co-efficients of the two primary and secondary systems. During the time interval when a primary circuit, as P^1, is closed by the make and break device B^1 D B^2, the secondary circuit S^1 in inductive relation to it may be made to vibrate at a different and considerably higher rate, owing to the diminution of its co-efficient of self-induction through the mutual induction of the circuits, and by proper adjustments of the quantities above named four oscillations of suitable frequency are generated by the transmitter. This being the case, the receiving station may be provided with two sets of apparatus, as illustrated in Fig. 2, and there will then be four relays or devices as R^1 R^2, which may be co-operatively connected or associated either in the manner shown in Fig. 2 or in any other convenient way, but so, that the desired effect upon a receiver will be produced only when all four receiving circuits are energized, and will not take place under any other circumstances.

When it is desired to modify the apparatus as and for the purpose above stated, the various quantities may be determined as follows: Designating, for the sake of convenience, by letters D^1 and S^1 respectively the terminal capacity and the inductance of the secondary system, its fundamental note, when the primary is open, will be of a suitably selected period $T^1 = \frac{1}{n^1 k} = \frac{2\pi}{10^3}\sqrt{4 D^1 S^1}$ D^1 expressing the capacity of the elevated terminal in microfarads and S^1 the inductance of the secondary coil in Henrys. In conformity with the preceding the influence of the primary circuit should be so regulated that, when it is closed by the make and break device D the vibration in the secondary will be of a smaller and arbitrarily chosen period $T^2 = \frac{1}{n^2 k}$ such that $\frac{T^1}{T^2} = \frac{\frac{1}{n^1 k}}{\frac{1}{n^2 k}} = \frac{n^2}{n^1}$, n^2 and n^1 being, preferably, small relative prime numbers and k a constant.

Designating further, conveniently, the inductance of the primary turn or turns in inductive relation to the secondary by the letter P^1, and the mutual induction co-efficient by M, the inductance of the secondary, when the primary circuit is closed, will be reduced to a value $S^1\left(1 = \frac{M^2}{P^1 S^1}\right)$ and the period will be approximately $T^2 = \frac{2\pi}{10^3}\sqrt{4 D^1 S^1 \left(1 - \frac{M^2}{P^1 S^1}\right)}$ Similarly, if letters C^1 and L^1 denote respectively the capacity in the primary circuit and inductance of the adjustable primary coil, the period of the primary circuit will likewise be $T^2 = \frac{2\pi}{10^3}\sqrt{C^1\left[L^1 + P^1\left(1 - \frac{M^2}{P^1 S^1}\right)\right]}$

Either of the two expressions found for T^2 may be used in the determinations of the quantities, but the latter is preferable, and it will be found most suitable in practice to ascertain the constants C^1, P^1, M and S^1 by measurement and calculate the approximate number of turns of coil L^1, which permits of easy and precise adjustment by actual experiment.

The above given values for the two periods of the resonating grounded system as D^1 S^1 E hold good only when the conductors, as S^1, are directly connected to the ground. When, as the case may be, a condenser is interposed in the ground connection, the values will be modified in a way well known to experts.

A difficulty may be experienced in securing the proper attunement of a number of circuits of different periods when, as in the instance last described, they are excited through a common medium or channel. The task will be facilitated by graduating the effects in the circuits, which may be done by the adjustment of the ratio of the inductance to the resistance, or otherwise. As a rule it will be found desirable to equalize the actions of the several circuits as much as possible. In connection with the above it is useful to state, that an advantage may be secured by the employment of a circuit-making and breaking device, similar to that illustrated in Fig. 5, for the purpose of connecting the four receiving circuits intermittently to the ground, instead of permanently, it being understood, of course, that the effect of the various circuits upon the receiver is practically simultaneous. Such a device is valuable also in ordinary systems, as, for instance, when it is desired to receive signals from a number of stations at the same time.

By using a transmitter emitting four different vibrations or classes of impulses distinctive in their effect upon as many elements of a receiver, eleven receiving stations can be operated, that is, six by combining two of the vibrations, with great safety, four by combining three of the vibrations, with a safety enormously increased, and one by combining all the four vibrations with a safety which, for most practical purposes, may be considered absolute. The various receivers will obviously be distributed to suit the importance of the several stations. The degree of safety, as well as the number of stations which may be selectively operated, can be still further increased by producing the impulses at the transmitting stations in any arbitrary order of succession which, if desired, may be continuously varied, and using them, at the various receiving stations, to actuate the receivers, in accordance with a predetermined understanding, code, key or safety combination.

Obviously transmitters and receivers may be provided with a much greater number of distinctive elements which, combined and associated in every possible way, will permit the selective operation of a practically unlimited number of devices through a common natural or artificial channel, and such a degree of individualization of a receiver, that it will be absolutely secure against extraneous interference and may be safely called into action, whenever desired, from among innumerable devices of its kind.

It will be seen from a consideration of the nature and purposes of the invention, that it is applicable not only to the special system described, in which the transmission of the impulses is effected through the natural media, but to other systems for the transmission of telegraphic or telephonic signals or of energy for any purpose, and whatever be the medium through which the impulses are transmitted, that is to say, the broad principle of making the operation of a receiver dependent upon the conjoint or resultant action of two or more electrically different or tuned circuits is applicable not only to the special system of telegraphy described in which the electrical energy is transmitted through the natural media, but also to such systems as involve the use of a cable or wire as the conducting medium. Moreover, it is not necessary that the energy transmitted should be utilized to operate any special form of telegraphic instrument, or in fact any telegraphic instrument at all, as the receiver may be a relay or similar device which controls any other kind of device, such for example as the steering mechanism of a self propelled vessel. Therefore the invention is, broadly considered, one for the transmission and utilization in a special manner of electrical energy in general.

Improvements in and relating to the Transmission of Electrical Energy.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

1. In a system for the transmission of energy, the combination with a receiver comprising a plurality of elements and dependent for operation upon their conjoint action, of a means for producing a plurality of distinctive kind of disturbances or impulses, severally adapted to actuate the elements of the receiver, as set forth.

2. In a system for the transmission of electrical energy, the combination with a receiver comprising a plurality of elements and dependent for operation upon their conjoint action, of a transmitter having a plurality of elements capable of severally producing distinctive kinds of disturbances or impulses, each kind being adapted to actuate one only of the elements of the receiver, as set forth.

3. In a system for the transmission of electrical energy, the combination with a receiver comprising a plurality of elements and dependent for operation upon the conjoint action of two or more of the same, of a transmitter adapted to produce a plurality of distinctive kinds of disturbances or impulses, each kind being adapted to actuate one only of the elements of the receiver, as set forth.

4. In a system for the transmission of electrical energy, the combination with means for producing two or more distinctive kinds of disturbances or impulses, of receiving circuits, each adapted to respond to the waves or impulses of one kind only, and a receiving device dependent for operation upon the conjoint action of the several receiving circuits, as set forth.

5. In a system for the transmission of electrical impulses and the operation or control of signalling or other apparatus thereby, the combination with a transmitter adapted to produce two or more distinctive kinds or classes of disturbances or impulses, of sensitive receiving circuits, each adapted to respond to the impulses or disturbances of one kind or class only, and a receiving device dependent for operation upon the conjoint action of the sensitive circuits, as set forth.

6. In a system for the transmission of electrical impulses, and the operation or control of signalling, or other apparatus thereby, the combination with a transmitter adapted to produce two or more distinctive kinds or classes of disturbances or impulses, of sensitive circuits at the receiving point or station, each adapted to respond to the impulses or disturbances of one kind or class only, a local circuit arranged to be completed by the conjoint action of the sensitive circuits and a receiving device connected therewith, as set forth.

7. In a system for the transmission of electrical impulses and the operation or control of signalling or other apparatus thereby, the combination with a transmitting apparatus adapted to produce two or more distinctive kinds of disturbances or impulses, of means for varying the relations of the impulses of the several kinds, sensitive circuits each adapted to respond to the impulses or disturbances of one kind only, and a receiving apparatus dependent for operation upon the conjoint action of the sensitive circuits, as set forth.

8. In a system, such as herein described, the combination with a transmitter adapted to produce a plurality of distinctive kinds of electrical disturbances or impulses, of a receiving apparatus comprising a plurality of circuits, a sensitive device and a relay included in each circuit, and adjusted to respond to the impulses or disturbances of one kind only, and a receiving apparatus in a local circuit controlled by the relays and adapted to be completed by the conjoint action of all of said relays, as set forth.

9. In a system of the kind described, the combination with a transmitter adapted to produce two or more series of electrical oscillations or impulses of different frequencies, of a receiving apparatus comprising a plurality of sensitive circuits each tuned to respond to the impulses of one of the series produced by the transmitter, and a signalling device dependent for its operation upon the conjoint action of said circuits, as set forth.

10. The combination with a plurality of transmitter elements, each adapted to produce a series of impulses or disturbances of a distinctive character, and means for controlling and adjusting the same, of a receiver having a plurality of sensitive circuits each adapted to be affected by one of the series of impulses only, and dependent for operation upon the conjoint action of all of said circuits, as set forth.

11. The combination with a transmitter adapted to produce series of electrical impulses or disturbances of distinctive character and in a given order of succession, of a receivng apparatus comprising elements adapted to respond to such impulses in a corresponding order, and dependent for operation upon the conjoint action of said elements, as set forth.

12. In a receiving apparatus, the combination of a plurality of sensitive circuits, each tuned to respond to waves or impulses of a given kind or class, a receiving circuit controlled by the sensitive circuits and a device connected with the receiving circuit adapted to be operated when said circuit is completed by the conjoint action of two or more of the sensitive circuits, as set forth.

13. The method of operating distant receivers which consists in producing and transmitting a plurality of kinds or classes of electrical waves or impulses, actuating by the waves or impulses of each class one of the elements of a receiver, and controlling the operation of the receiver by the conjoint action of two or more of said elements, as set forth.

14. The method of signalling which consists in producing and transmitting a plurality of kinds or classes of electrical waves or impulses, developing by the waves or impulses of each class a current in one of a plurality of receiving circuits and controlling by means of such circuits a local circuit, as set forth.

15. The method of signalling which consists in producing a plurality or series of waves or impulses differing from each other in character or order of succession, exciting by the waves or impulses of each series one of a plurality of receiving circuits and controlling by such circuits a local circuit, as set forth.

16. The method of signalling which consists in producing a plurality or series of waves or impulses, varying the character or order of succession of the several series, exciting by the waves or impulses of each series one of a plurality of receiving circuits and controlling by such circuits a local circuit, as set forth.

Dated this 16th day of July 1901.

HASELTINE, LAKE & Co.,
45-Southampton Buildings, London, W.C.,
Agents for the Applicant.

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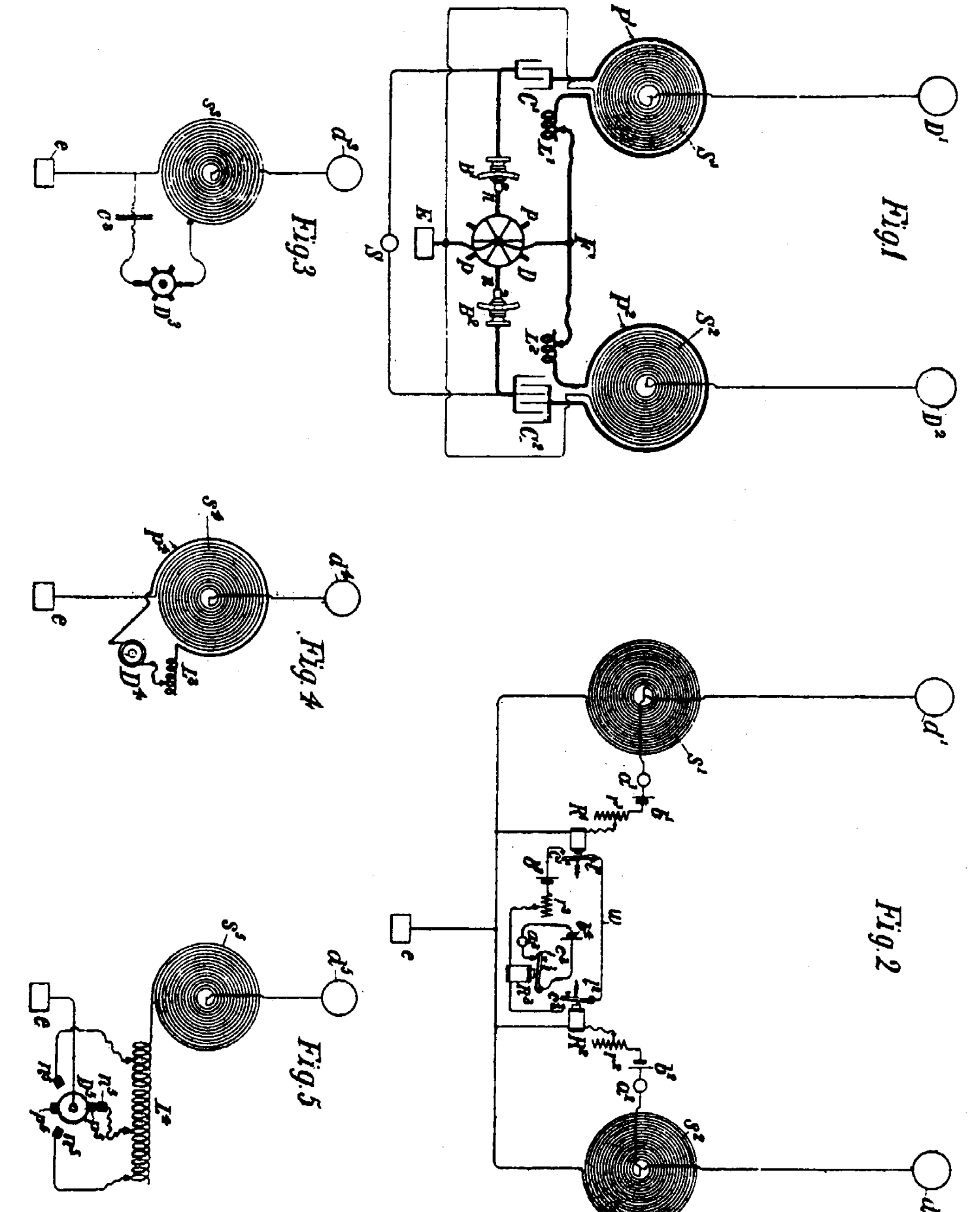
Fig.1
Fig.2
Fig.3
Fig.4
Fig.5

[Second Edition.]

N° 16,709 A.D. 1889

Date of Application, 22nd Oct., 1889—Accepted, 7th Dec., 1889

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of New York, in the County and State of New York, United States of America, Electrician.]

Improvements relating to the Conversion of Alternating into Direct Electric Currents.

I, HENRY HARRIS LAKE, of the firm of Haseltine Lake & Co. Patent Agents, Southampton Buildings in the County of Middlesex do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In nearly all the more important industrial applications of electricity, the current is produced by dynamo-electric machines driven by power, in the coils of which the currents developed are primarily in reverse directions or what is known as alternating. As many electrical devices and systems, however, require direct current, it has been usual to correct the current alternations by means of a commutator instead of taking them off directly from the generating coils.

The superiority of alternating current machines in all cases where their currents can be used to advantage, renders their employment very desirable as they may be much more economically constructed and operated, and the object of this invention is to provide means for directing or converting at will at one or more points in a circuit, alternating into direct currents.

Stated broadly, the invention consists in obtaining direct from alternating currents, or in directing the waves of an alternating current so as to produce direct or substantially direct currents, by developing or producing in the branches of the circuit including a source of alternating currents, either permanently or periodically and by electric, electro-magnet or magnetic agencies, manifestations of energy or what may be termed active resistances of opposite electrical character, whereby the currents or current waves of opposite sign or direction will be diverted through different circuits, those of one sign passing over one branch and those of opposite sign over another.

The case of a circuit divided into two paths only may be considered herein inasmuch as any further subdivision involves merely an extension of the same general principle.

Selecting then, any circuit through which is flowing an alternating current, let such circuit be divided at any desired point into two branches or paths. In one of these paths is inserted some device to create an electro-motive force opposed to the waves or impulses of current of one sign, and a similar device in the other branch which opposes the waves of opposite sign. Suppose for example, that these devices are batteries, primary or secondary, or continuous current dynamo machines. The waves or impulses of opposite direction, composing the main current, have a natural tendency to divide between the two branches, but by reason of the opposite electrical character or effect of the two branches, one will offer an easy passage to a current of a certain direction, while the other will offer a relatively high resistance to the passage of the same current. The result of this distribution is that the waves of current of one sign will—partly or wholly—pass over one of the paths or branches while those of the opposite sign pass over the other.

There may thus be obtained from an alternating current two or more direct currents, without the employment of any commutator such as it has been heretofore regarded as necessary to use. The current in either branch may be used in the same way and for the same purposes as any other direct current, that is, it may be made to charge secondary batteries, energize electro-magnets, or used for any other analogous purpose.

Some of the various ways in which this invention may be carried into practice is illustrated diagramatically in the accompanying drawings the figures of which are hereinafter referred to.

Figure 1 represents a plan of directing the alternating currents by means of devices purely electrical in character. A designates a generator of alternating currents and B B, the main or line circuit therefrom.

At any given point in this circuit at or near which it is desired to obtain direct currents, the circuit B is divided into two paths or branches C. D. In each of these branches is placed an electrical generator which for the present may be assumed to produce direct or continuous currents.

The direction of the current thus produced is opposite in one branch to that of the current in the other branch, or considering the two branches, as forming a closed circuit, the generators E F are connected up in series therein, one generator in each part or half of the circuit.

The electromotive force of the current sources E and F may be equal to, or higher or lower than the electromotive forces in the branches C D or between the points X and Y of the circuit B B. If equal, it is evident that current waves of one sign will be opposed in one branch and assisted in the other to such an extent that all of the waves of one sign will pass over one branch and those of opposite sign over the other. If, on the other hand the electromotive force of the sources E, F, be lower than that between X and Y, the currents in both branches will be alternating, but the waves of one sign will preponderate.

One of the generators or sources of current E or F, may be dispensed with, but it is preferable to employ both, if they offer an appreciable resistance, as the two branches will be thereby better balanced. The translating or other devices to be acted upon by the current are designated by the letters G, and they are inserted in the branches C D in any desired manner, but in order to better preserve an even balance between the branches, due regard should be had to the number and character of the devices as will be well understood.

Figures 2, 3, 4 and 5 illustrate what may be termed electro-magnetic devices for accomplishing a similar result. That is to say, instead of producing directly by a generator an electromotive force in each branch of the circuit, a field or fields of force is established, and the branches led through the same in such manner that an active opposition of opposite effect or direction will be developed therein by the passage or tendency to pass of the alternations of current.

In Figure 2, for example, A is the generator of alternating currents B B, the line circuit, and C D the branches over which the alternating currents are directed. In each branch is included the secondary of a transformer or induction coil, which, since they correspond in their functions to the batteries of the previous figure are designated by the letters E F.

The primaries H H^1 of the induction coils or transformers are connected either in parallel or series with a source of direct or continuous current I, and the number of convolutions is so calculated for the strength of the current from I that the coils J J^1, will be saturated.

The connections, are such that the conditions in the two transformers are of opposite character, that is to say, the arrangement is such that a current wave or impulse corresponding in direction with that of the direct current in one primary as H, is of opposite direction to that in the other primary H^1, hence it results that while one secondary offers a resistance or opposition to a passage through it of a wave of one sign, the other secondary similarly opposes a wave of opposite sign. In consequence, the waves of one sign will, to a greater or less extent, pass by the way of one branch, while those of opposite sign in like manner pass over the other branch.

In lieu of saturating the primaries by a source of continuous current, they may be included in the branches C, D, respectively, and their secondaries periodically short-circuited by any suitable mechanical devices, such as an ordinary revolving commutator. It will be understood of course, that the rotation and action of the commutator must be in synchronism or in proper accord with the periods of the alternations in order to secure the desired results.

Such a disposition is represented diagrammatically in Figure 3. Corresponding to the previous Figures, A is the generator of alternating currents, B, B, the line and C D, the two branches for the direct currents. In branch C are included two primary coils E, E^1, and in branch D are two similar primaries F, F^1. The corresponding secondaries for these coils and which are on the same subdivided cores J or J^1, are in circuits, the terminals of which connect to opposite segments K, K^1 and L, L^1, respectively of a commutator. Brushes *b b* bear upon the commutator and alternately short-circuit the plates K and K^1 and L and L^1 through a connection *c*. It is obvious that either the magnets and commutator or the brushes may revolve.

The operation will be understood from a consideration of the effects of closing or short-circuiting the secondaries. For example, if at the instant when a given wave of current passes, one set of secondaries be short circuited nearly all the current flows through the corresponding primaries, but the secondaries of the other branch being open circuited, the self-induction in the primaries is highest and hence little or no current will pass through that branch. If as the currents alternates, the secondaries of the two branches are alternately short-circuited, the result will be that the currents of one sign pass over one branch and those of the opposite sign over the other.

The disadvantages of this arrangement which would seem to result from the employment of sliding contacts, is in reality very slight, inasmuch as the electromotive force of the secondaries may be made exceedingly low so that sparking at the brushes is avoided.

Figure 4 is a diagram partly in section of another plan of carrying out the invention.

The circuit B in this case is divided as before and each branch includes tha coils of both the field and revolving armatures of two induction devices. The armatures O P, are preferably mounted on the same shaft, and are adjusted relatively to one another in such manner that when the self-induction in one branch as C is maximum, in the other branch D it is minimum.

The armatures are rotated in synchronism with the alternations from the source A. The winding or position of the armature coils is such that a current in a given direction passed through both armatures would establish in one, poles similar to those in the adjacent poles of the field, and in the other, poles unlike the adjacent field poles, as indicated by *n*, *n*, *s*, *s*, in the drawing.

If the like poles are presented as shown in circuit D, the condition is that of a closed secondary upon a primary, or the position of least inductive resistance, hence a given alternation of current will pass mainly through D. A half revolution of the armatures produces an opposite effect and the succeeding current impulse passes through C.

Using this figure as an illustration it is evident that the fields N, M, may be permanent magnets or independently excited and the armatures O, P, driven as in the present case so as to produce alternate currents which will set up alternately, impulses of opposite direction in the two branches D. C, which in such case would include the armature circuits and translating devices only.

In Figure 5 a plan alternative with that shown in Figure 3 is illustrated. In the previous case illustrated, each branch C and D contained one or more primary coils, the secondaries of which were periodically short-circuited, in synchronism with the alternations of current from the main source A, and for this purpose a commutator was employed. The latter, may, however, be dispensed with, and an armature with a closed coil substituted.

Referring to Figure 5, in one of the branches, as C, are two coils M^1 wound on laminated cores and in the other branches D are similar coils N^1. A subdivided or laminated armature O^1 carrying a closed coil R^1 is rotably supported between the coils M^1 N^1 as shown.

In the position shown, that is with the coil R^1 parallel with the convolutions of the primaries N^1 N^1, practically the whole current will pass through branch D, because the self-induction in coils M^1 M^1 is maximum. If, therefore, the armature and coil be rotated in synchronism with the alternations of the source A the same results are obtained as in the case of Figure 3.

Figure 6 is an instance of what may be called in distinction to the others, a magnetic means of securing the results arrived at in this invention. V and W are two strong permanent magnets, provided with armatures V^1 W^1 respectively. The armatures are made of thin laminae of soft iron or steel, and the amount of magnetic metal which they contain is so calculated that they will be fully or nearly saturated by the magnets. Around the armatures are coils E F, contained respectively in the circuits C and D.

The connections and electrical conditions in this case are similar to those in Figure 2, except that the current source I of Figure 2 is dispensed with and the saturation of the core of coils E F obtained from the permanent magnets.

In the illustrations heretofore given, the two branches or paths containing the translating or induction devices are in each instance shown as in derivation one to the other, but this is not always necessary. For example, in Figure 7, A is an alternating current generator; B, B, the line wires or circuit. At any given point in the circuit two paths as D D^1, are formed, and at another point two paths as C C^1. Either pair of group of paths is similar to the previous dispositions with the electrical source or induction device in one branch only, while the two groups taken together form the obvious equivalent of the cases in which an induction device or generator is included in both branches.

In one of the paths as D are included the devices to be operated by the current. In the other branch as D^1 is an induction device that opposes the current impulses of one direction and directs them through the branch D. So also in branch C are translating devices G and in branch C^1 an induction device or its equivalent that diverts through C, impulses of opposite direction to those diverted by the device in branch D^1.

A special form of induction device for this purpose is also shown. J J^1 are the cores formed with pole pieces upon which are wound the coils M N. Between these pole pieces are mounted at right angles to one another the magnetic armatures O P, preferably mounted on the same shaft and designed to be rotated in synchronism with the alternations of current. When one of the armatures is in line with the poles or in the position occupied by armature P, the magnetic circuit of the induction device is practically closed, hence there will be the greatest opposition to the passage of a current through coils N N. The alternation will therefore pass by way of branch D; at the same time, the magnetic circuit of the other induction device being broken by the position of the armature O, there will be less opposition to the current in coils M, which will shunt the current from branch C.

A reversal of the current being attended by a shifting of the armatures the opposite effect is produced.

There are many other modifications of the means or methods of carrying out this invention, but it is not deemed necessary herein to specifically refer to more than those described as they involve the chief modifications of the plan. In all of these it will be observed that there is developed in one or all of the branches of a circuit from a source of alternating currents an active (as distinguished from a dead) resistance, or opposition to the currents of one sign, for the purpose of diverting the currents of that sign through the other or another path, but permitting the currents of opposite sign to pass without substantial opposition.

Whether the division of the currents or waves of current of opposite sign be effected with absolute precision or not is immaterial to the invention since it will be sufficient if the waves are only partially diverted or directed, for in such case the preponderating influence in each branch of the circuit of the waves of one sign secures the same practical results in many if not all respects as though the current were direct and continuous.

An alternating and direct current have been combined so that the waves of one direction or sign were partially or wholly overcome by the direct current, but by this plan only one set of alternations are utilized, whereas by this system the entire current is rendered available.

By obvious applications of this discovery, it is possible to produce a self-exciting alternating dynamo, or to operate direct current meters on alternating current circuits, or to run various devices, such as arc lamps, by direct currents in the same circuit with incandescent lamps or other devices run by alternating currents.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed as communicated to be by my foreign correspondent I declare that what I claim is:—

First. The method herein set forth of obtaining direct from alternating currents, which consists in developing or producing in one branch of a circuit from an alternating current source an active resistance to the current impulses of one direction, whereby the said currents or waves of current will be diverted or directed through another branch.

Second. The method of obtaining direct from alternating currents, which consists in dividing the path of an alternating current into branches and developing in one of said branches, either permanently or periodically, an electrical force or active resistance counter to or opposing the currents or current waves of one sign, and in the other branch a force counter to or opposing the currents or current waves of opposite sign, as set forth.

Third. The method of obtaining direct from alternating currents, which consists in dividing the path of the alternating current into branches, establishing fields of force and leading the said branches through said fields of force in substantially the manner set forth, whereby electro-motive forces of opposite direction will be produced therein.

Fourth. The combination with the branches of a divided circuit carrying alternating currents, of devices included in or connected with the said branches and capable of developing or exerting an active opposition or electro-motive force counter to the current waves of one direction or sign, as herein set forth.

Dated this 22nd day of October 1889.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, Agents for the Applicant.

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[G. 4544—50—3/99.]

A.D. 1889. Oct. 22. N° 16,709.
LAKE'S Complete Specification.

(2nd Edition)

Fig. 1

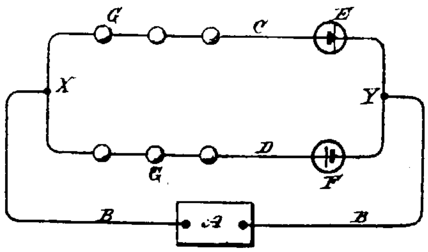


Fig. 2

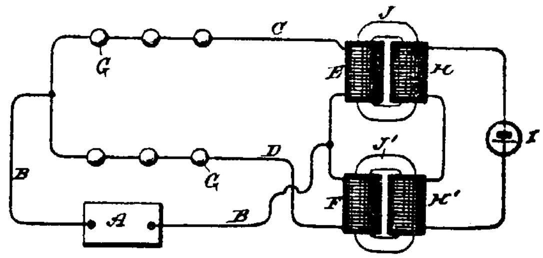


Fig. 3

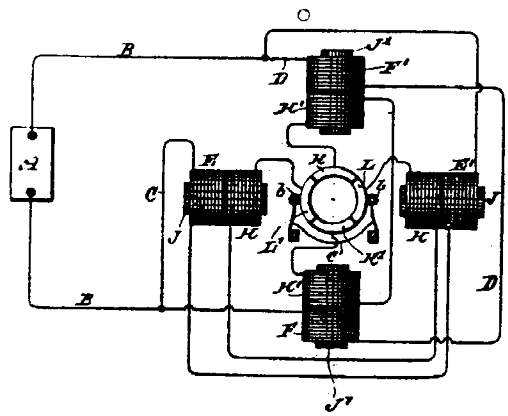


Fig. 4

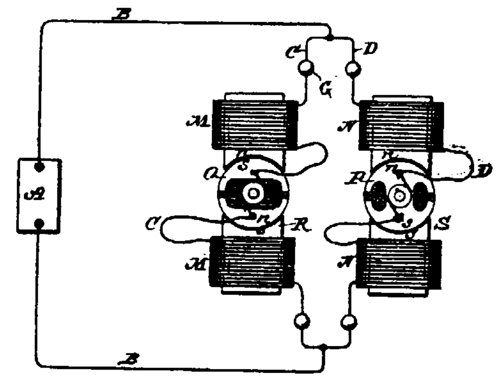


Fig. 5

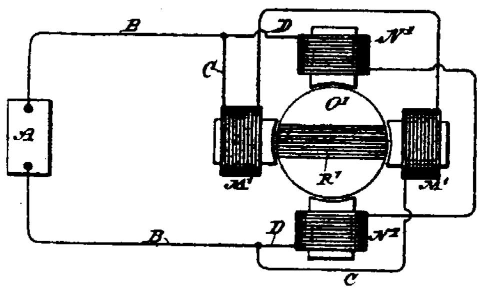


Fig. 6

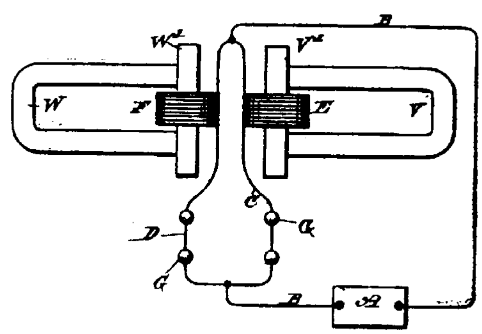
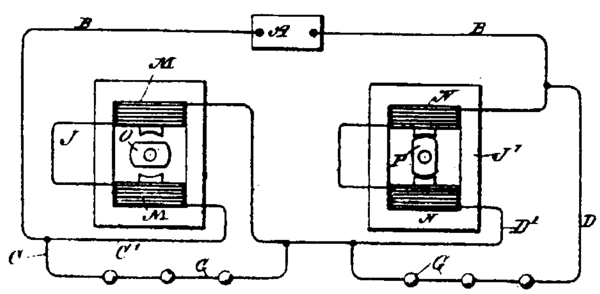


Fig. 7



[Third Edition.]

N° 19,420 A.D. 1889

Date of Application, 3rd Dec., 1889—Accepted, 11th Jan., 1890

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of the City and State of New York, United States of America, Electrician.]

Improvements in Alternating Current Electro-magnetic Motors.

I, HENRY HARRIS LAKE, of the firm of Haseltine, Lake & Co., Patent Agents, Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to that form of alternating current motor in which there are two or more energizing circuits through which alternating currents differing in phase are caused to pass.

Various forms or types of this motor are now known to the public. First, motors having two or more energizing circuits of the same electrical character and in the operation of which the currents used differ primarily in phase. Second, motors with a plurality of energizing circuits of different electrical character, in or by means of which the difference of phase is produced artificially, and third, motors with a plurality of energizing circuits, the currents in one being induced from currents in another. The application of the present invention to these several types will be shown.

Considering the structural and operative conditions of any one of them, as for example that first named, the armature which is mounted to rotate in obedience to the cooperative influence or action of the energizing circuits, has coils wound upon it which are closed upon themselves, and in which currents are induced by the energizing currents with the object and result of energizing the armature core.

But under any such conditions as must exist in these motors, it is obvious that a certain time must elapse between the manifestations of an energizing current impulse in the field coils, and the corresponding magnetic state or phase in the armature established by the current induced thereby, consequently a given magnetic influence or effect in the field which is the direct result of a primary current impulse, will have become more or less weakened or lost before the corresponding effect in the armature, indirectly produced, has reached its maximum. This is a condition unfavorable to efficient working in certain cases, as, for instance, when the progress of the resultant poles or points of maximum, attraction is very great, or when a very high number of alternations is employed, for it is apparent that a stronger tendency to rotation will be maintained if the maximum magnetic attractions or conditions in both armature and field coincide, the energy developed by a motor being measured by the product of the magnetic quantities of the armature and field.

The object, therefore, in this invention is to so construct or organize these motors that the maxima of the magnetic effects of the two elements, the armature and field, shall more nearly coincide.

This is accomplished in various ways, which, may be best explained by reference to the drawings, in which various plans for accomplishing the desired results are illustrated.

Figure 1. This is a diagrammatic illustration of a motor system in which the alternating currents proceed from independent sources and differ primarily in phase.

A designates the field, or magnetic frame of the motor, B, B, oppositely located pole pieces adapted to receive the coils of one energizing circuit and C, C, similar pole pieces for the coils of the other energizing circuit. These circuits are designated respectively by D, E, the conductor D^{11} forming a common return, to the generator G.

Between these poles is mounted an armature, for example a ring or annular armature wound with a series of coils F forming a closed circuit or circuits. The action or operation of a motor thus constructed is now well understood. It will be observed, however, that the magnetism of poles B, for example, established by a current impulse in the coils thereon precedes the magnetic effect set up in the armature by the induced current in coils F, consequently the mutual attraction between the armature and field poles is considerably reduced. The same conditions will, be found to exist, if, instead of assuming the poles B or C as acting independently, we regard the ideal resultant of both acting together, which is the real condition.

To remedy this the motor field is constructed with secondary poles B^1 C^1 which are situated between the others. These pole pieces are wound with coils D^1 E^1, the former in derivation to the coils D, the latter to coils E. The main or primary coils D and E are wound for a different self-induction from that of the coils D^1 and E^1, the relations being so fixed that if the currents in D and E differ, for example, by a quarter phase, the currents in each secondary coil as B^1 C^1 will differ from those in its appropriate primary B or C by say 45 degrees, or one eighth of a period.

The explanation of the action of this motor is as follows: Assuming that an impulse or alternation in circuit or branch E is just beginning while in the branch D it is just falling from maximum,—the conditions of a quarter phase difference; the ideal resultant of the attractive forces of the two sets of poles B, C, therefore may be considered as progressing from poles C to poles B while the impulse in E is rising to maximum and that in D is falling to zero or minimum. The polarity set up in the armature, however, lags behind the manifestations of field magnetism and hence the maximum points of attraction in armature and field instead of coinciding are angularly displaced. This effect is counteracted by the supplemental poles B^1 C^1. The magnetic phases of these poles succeed those of poles B C by the same, or nearly the same, period of time as elapses between the effect of the poles B C and the corresponding induced effect in the armature, hence the magnetic conditions of poles B^1 C^1 and of the armature more nearly coincide and a better result obtained. As poles B^1 C^1 act in conjunction with the poles in the armature established by poles B C, so in turn poles C B act similarly with the poles set up by B^1 C^1, respectively.

Under such conditions the retardation of the magnetic effect of the armature and that of the secondary poles will bring the maximum of the two more nearly into coincidence and a correspondingly stronger torque or magnetic attraction secured.

In such a disposition as is shown in Figure 1 it will be observed that as the adjacent pole pieces of either circuit are of like polarity they will have a certain weakening effect upon one another. It is therefore desirable to remove the secondary poles from the direct influence of the others. This may be done by constructing a motor with two independent sets of fields, and with either one or two armatures electrically connected, or by using two armatures and one field. These modifications will be illustrated hereinafter.

Figure 2 is a diagrammatic illustration of a motor and system in which the difference of phase is artificially produced.

There are two coils D D in one branch and two coils E E in the other branch of the main circuit from the generator G. These two circuits or branches are of different self induction, one, as D being higher than the other. For convenience this is indicated by making coils D much larger than coils E.

By reason of this difference in the electrical character of the two circuits the phases of current in one are retarded to a greater extent than the other. Let this difference be thirty degrees.

A motor thus constructed will rotate under the action of an alternating current, but as happens in the case previously described the corresponding magnetic effects of the armature and field do not coincide owing to the time that elapses between a given magnetic effect in the armature and the condition of the field that produces it. The secondary or supplemental poles B^1 C^1 are therefore employed.

There being a thirty degrees difference in phase between the currents in coils D E the magnetic effects of poles B^1 C^1 should correspond to that produced by a current differing from the current in coils D or E by 15 degrees. This may be accomplished by winding each supplemental pole B^1 C^1 with two coils H, H^1. The coils H are included in a derived circuit having the same self-induction as circuit D and coils H^1 in a circuit having the same self-induction as circuit E, so that if these circuits differ by 30 degrees the magnetism of poles B^1 C^1 will correspond to that produced by a current differing from that in either D or E by 15 degrees.

This is true in all other cases, for example, if in Figure 1 the coils D^1 E^1 be replaced by the coils H H^1 included in derived circuits, the magnetism of the poles B^1 C^1 will correspond in effect or phase if it may be so termed, to that produced by a current differing from that in either circuit D or E by 45 degrees or one-eighth of a period.

This invention as applied to a derived circuit motor is illustrated in Figures 3 and 4. The former is an end view of the motor with the armature in section, and a diagram of connections, and Figure 4 a vertical section through the field.

These figures are also drawn to show one of the dispositions of two fields that may be adopted in carrying out the invention.

The poles B B, C C, are in one field, the remaining poles in the other. The former are wound with primary coils I J and secondary coils I^1 J^1, the latter with coils K L. The primary coils I J are in derived circuits between which, by reason of their different self-induction, there is a difference of phase, say of 30 degrees. The coils I^1 K^1 are in circuit with one another, as also are coils J^1 *l* and there should be a difference of phase between the currents in coils K and L and their corresponding primaries of, say, 15 degrees.

If the poles B C are at right angles the armature coils should be connected directly across, or a single armature core wound from end to end may be used, but if the poles B C be in line there should be an angular displacement of the armature coils as will be well understood.

The operation will be understood from the foregoing. The maximum magnetic condition of a pair of poles as B^1 B^1 coincides closely with the maximum effect in the armature, which lags behind the corresponding condition in poles B B.

There are many other ways of carrying out this invention, but they all involve the same broad principle of construction and operation.

In using expressions herein to indicate a coincidence of the magnetic phases or effects in one set of field magnets with those set up in the armature by the other, approximate results only are meant, but this of course will be understood.

In these and similar motors the total energy supplied to effect their operation is equal to the sum of the energies expended in the armature and the field.

The power developed, however, is proportionate to the product of these quantities. This product will be greatest when these quantities are equal, hence, in constructing a motor it is desirable to determine the mass of the armature and field cores and the windings of both and adapt the two so as to equalize as nearly as possible the magnetic quantities of both.

In motors which have closed armature coils, this is only approximately possible as the energy manifested in the armature is the result of inductive action from the other element, but in motors in which the coils of both armature and field are connected with the external circuit, the result can be much more perfectly obtained.

In further explanation of this object let it be assumed that the energy as represented in the magnetism in the field of a given motor is 90 and that of the armature 10. The sum of these quantities which represents the total energy expended in driving the motor is 100. But assume that the motor be so constructed that the energy in the field is represented by 50, and that in the armature by 50, the sum is still 100, but while in the first instance the product is 900, in the second it is 2,500, and as the energy developed is in proportion to these products, it is clear that those motors are the most efficient, other things being equal, in which the magnetic energies developed in the armature and field are equal.

These results may be obtained by using the same amount of copper or ampere turns in both elements, when the cores of both are equal or approximately so, and the same current energizes both. Or, in cases where the currents in one element are induced by those of the other, by using in the induced coils an excess of copper over that in the primary element or conductor.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed as commmunicated to me by my foreign correspondent I declare that what I claim is,—

1. In an alternating current motor the combination with an armature wound with closed coils, of main and supplemental field magnets or poles, one set of which is adapted to exhibit their maximum magnetic effect simultaneously with that set up in the armature by the action of the other, as set forth.

2. In an electro-magnetic motor the combination with an armature of a plurality of field or energizing coils included respectively in main circuits adapted to produce a given difference of phase and supplementary or secondary circuits adapted to produce an intermediate difference of phase, as set forth.

3. An electro-magnetic motor in which the field and armature magnets exhibit equal strength or magnetic quantities under the influence of a given energizing current, as set forth.

4. In an alternating current motor, the combination with field and armature cores of equal mass of energizing coils containing equal amounts of copper as herein set forth.

Dated this 3rd day of December 1889.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, Agents for the Applicant.

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[G. 6345—50—1/1902].

A.D. 1889. Dec. 3. N° 19,420
LAKE'S Complete Specification.

(3rd Edition)

Fig. 1

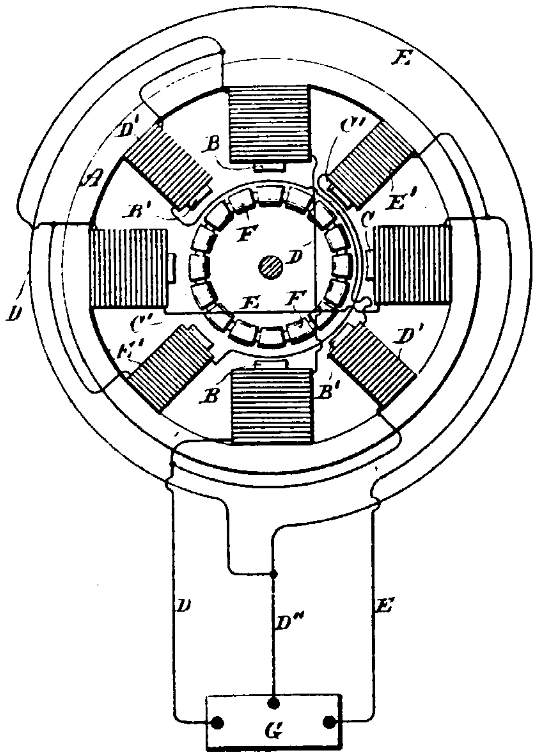


Fig. 2

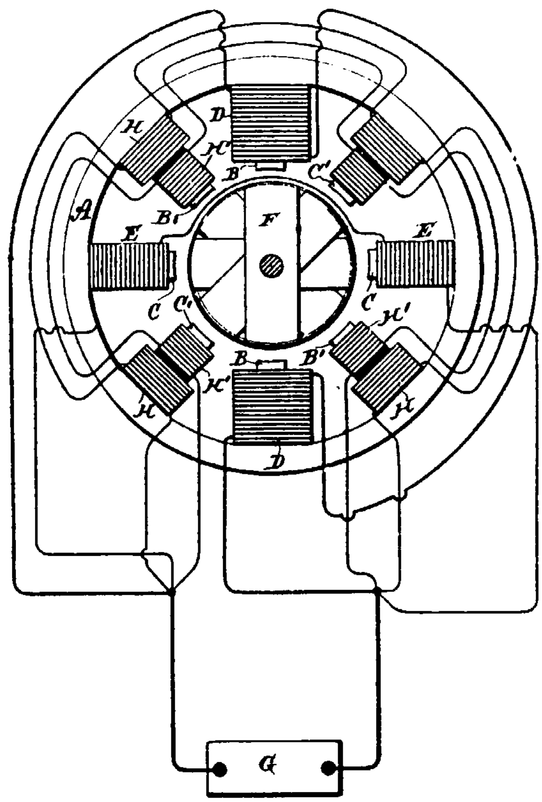


Fig. 3

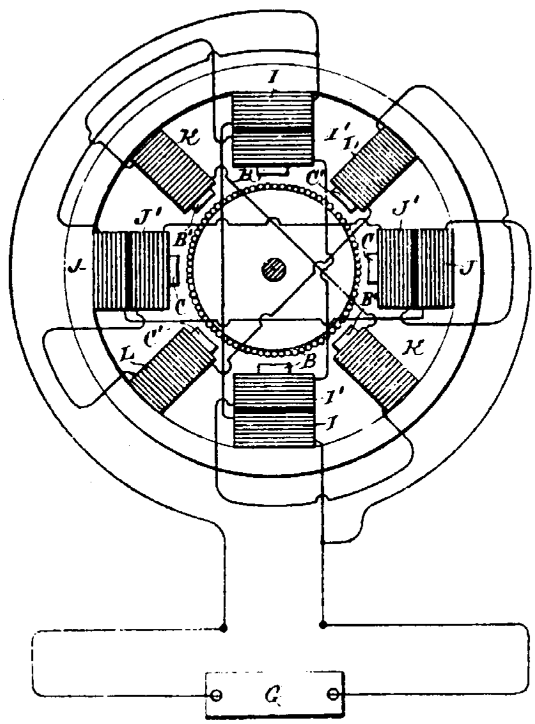
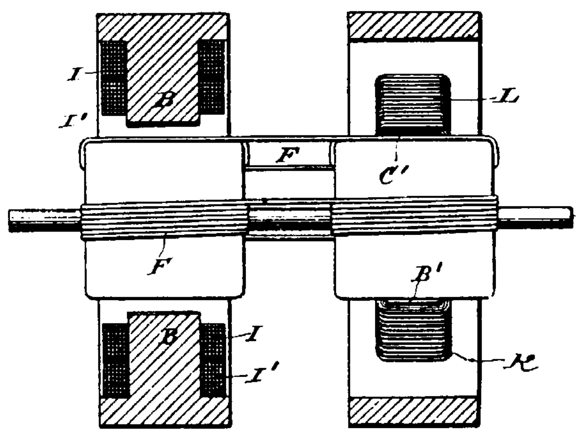


Fig. 4



[Third Edition.]

N° 19,426 A.D. 1889

Date of Application, 3rd Dec., 1889—Accepted, 11th Jan., 1890

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of the City and State of New York, United States of America, Electrician.]

Improvements in the Construction and Mode of Operating Alternating Current Motors.

I, HENRY HARRIS LAKE, of the firm of Haseltine, Lake & Co., Patent Agents, Southampton Buildings in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to that form of electro-magnetic motors in which one of the elements, the armature or the field, is provided with coils forming independent energizing circuits, through which from any suitable source or sources, alternating currents differing in phase, are passed for the purpose of producing in the motor a progression or rotation of the points of maximum magnetic attraction.

Motors of this general character are constructed in various ways, the principal forms being, 1st, those in which the independent energizing circuits are connected to independent sources of alternating currents having a definite difference in phase; 2nd, those in which the independent energizing circuits are of different electrical character, or have different degrees of self-induction, and are connected in derivation to the same source or circuit of alternating currents; and 3rd, those having independent energizing circuits in mutually inductive relations whereby alternating currents passed through one circuit will induce similar currents in the other.

This invention relates mainly to the two kinds of motor last named; that is to say, to those which are run by a single source of alternating currents or in which the currents in the two energizing circuits are derived either directly or indirectly from one line or main circuit.

The lag or retardation of the phases of an alternating current is directly proportional to the self induction and inversely proportional to the resistance of the circuit through which the current flows. Hence, in order to secure the proper difference of phase between the two motor circuits, it is desirable to make the self induction in one much higher, and the resistance much lower, than the self induction and resistance respectively in the other. At the same time the magnetic quantities of the two poles or sets of poles which the two circuits produce should be approximately equal. These requirements which exist in motors of this kind have led to the invention of a motor having the following general characteristics.

The coils which are included in that energizing circuit which is to have the higher self-induction are made of coarse wire, or a conductor of relatively low resistance, and the greatest possible length or number of turns is used.

In the other set of coils are a comparatively few turns of finer wire or a wire of higher resistance. Furthermore, in order to approximate the magnetic quantities of the poles excited by these coils, the cores in the self induction circuit are much longer than those in the other or resistance circuit. A motor embodying these features is shown in the accompanying drawing in which

Figure 1 is a part sectional view of the motor at right angles to the shaft. Figure 2 is a diagram of the field circuits.

In Figure 2, let A represent the coils in one motor circuit and B those in the other. The circuit A is to have the higher self induction. A long length of a large number of turns of coarse wire is therefore used in forming the coils of this circuit.

For the circuit B, a smaller conductor, or a conductor of a higher resistance than copper, such as German silver or iron, is employed, and the coils have fewer turns.

In applying these coils to a motor, a field is built up of plates C of iron or steel, secured together in the usual manner by bolts D. Each plate is formed with four—more or less—long cores E, around which is a space to receive the coil, and an equal number of short projections F to receive the coils of the resistance circuit. The plates are generally annular in shape, forming an open space in the center for receiving the armature G.

An alternating current divided between the two circuits is retarded as to its phases in the circuit A to a much greater extent than in the circuit B. By reason of the relative sizes and disposition of the cores and coils, the magnetic effect of the poles E and F upon the armature closely approximate. These conditions are well understood and readily secured by one skilled in the art.

An important result secured by the construction herein shown of the motor is that those coils which are designed to have the higher self-induction are almost completely surrounded by iron by which the retardation is considerably increased.

Heretofore in the construction of motors operating according to this principle, it has been customary to wind the armature with coils closed upon themselves, except in some instances in which the energizing circuits are connected to independent sources of alternating currents and the armature coils are also connected to the same sources But for some purposes it is advantageous to include both armature and field circuits in a circuit from a single source of current, as is shown in Figure 3, which is a diagram of the circuit connections.

A, B, in this figure, indicate the two energizing circuits of a motor, and A^1, B^1, two circuits on the armature. Circuit or coil A is connected in series with circuit or coil A^1, and the two circuits B, B^1 are similarly connected.

Between coils A and A^1 is a contact ring *e* forming one terminal of the latter and a brush *a* forming one terminal of the former. A ring *d* and brush *c* similarly connect coils B and B^1. The opposite terminals of the field coils connect to one binding post *h* of the motor, and those of the armature coils are similarly connected to the opposite binding post *i* through a contact ring *f* and brush *g*.

Thus each motor circuit while in derivation to the other includes one armature and one field coil. These circuits are of different self induction, and may be made so in various ways. For the sake of clearness there is shown in one of these circuits an artificial resistance R, and in the other a self-induction coil S.

When an alternating current from a generator H is passed through this motor, it divides between its two energizing circuits. The higher self-induction of one circuit produces a greater retardation or lag in the current therein than in the other. The difference of phase between the two currents effects the rotation or shifting of the points of maximum magnetic effect that secures the rotation of armature.

In certain respects this plan of including both armature and field coils in circuit, is a marked improvement. Such a motor has a good torque at starting, yet it has also considerable tendency to synchronism, owing to the fact that, when properly constructed, the maximum magnetic effects in both armature and field coincide, a condition which in the usual coustruction of these motors will close armature coils, is not readily attained. The motor thus constructed, exhibits too, a better regulation of current from no load to load, and there is less difference between the apparent and real energy expended in running it. The true synchronous speed of this form of motor is that of the generator, when both are alike. That is to say, if the number of the coils on the armature and on the field is x the motor will run normally at the same speed as a generator driving it if the number of field magnets or poles of the same be also x.

The arrangement of the coils with reference to one another may be considerably varied. For example, the two armatures and two field coils instead of being connected together in series in two derived circuits, may be in derivation to themselves and in series with one another as shown in Figure 4. In this figure, A, B, are the field coils, opposite terminals of which are connected to the binding post *h* on one side and binding post *i* on the other through brushes and collecting rings and the armature coils A^1, B^1. These latter are in derived circuits of different self induction which are shown as containing a dead resistance R^1 and a self-induction coil S^1.

Figure 5 shows a further modification, in which the armature has but one coil C^1 in series with the field coils which are in derivation to one another. The winding of the coil C^1 in this case should be such as to maintain effects corresponding to the resultant poles produced by the two field circuits.

In like manner the armature and field coils may all be derived or multiple circuits having the proper relative self-induction, or one of the armature circuits may be closed upon itself and the other connected either in derivation or series with the field coils.

A motor constructed in this way with its field and armature coils connected with the external circuits, exhibits a strong tendency to synchronism, but comparatively little torque on the start. On the other hand, if the armature coils be short circuited, the torque in starting is very greatly increased, but the tendency to run in synchronism with the generator is correspondingly reduced. For the proper operation of these motors, therefore, a shunt K is used around one or both of the armatures coils in which is placed a switch L.

In starting this motor the shunt around the armature coils is closed, so that the latter, therefore, will be in closed circuit. When the current is directed through the motor it divides between the two circuits—it is not necessary to consider any case where there are more than two circuits used—which by reason of their different self-induction secure a difference of phase between the two currents in the two branches that produces a shifting or rotation of the poles. By the alternations of current other currents are induced in the closed—or short circuited—armature coils, and the motor has a strong torque. When the desired speed is reached the shunt around the armature coils is opened and the current directed through both armature and field coils. Under these conditions, the motor has a strong tendency to synchronism.

It is of advantage in the operation of motors of this kind to construct or wind the armature in such manner, that when short circuited on the start, it will have a tendency to reach a higher speed than that which synchronizes with the generator. For example, a given motor, having say eight poles, should run, with the armature coil short circuited at 2000 revolutions per minute to bring it up to synchronism. It will generally happen, however, that this speed is not reached, owing to the fact that the armature and field currents do not properly correspond, so that when the current is passed through the armature—the motor not being quite up to synchronism—there is a liability that it would not " hold on " as it is termed. It is therefore preferable to so wind or construct the motor that on the start, when the armature coils are short circuited, the motor will tend to reach a speed higher than the synchronous, as for instance, double the latter. In such case the difficulty above alluded to is not felt, for the motor will always hold up to synchronism if the synchronous speed—in the case supposed of 2000 revolutions—is reached or passed.

This may be accomplished in various ways, but for all practical purposes the following will suffice. On the armature are wound two sets of coils, on the start one is short-circuited only, thereby producing a number of poles on the armature which will tend to run the speed up above the synchronous limit, when such limit is reached or passed the current is directed through the other coil which, by increasing the number of armature poles, tends to maintain synchronism.

This disposition has the advantage that the closed armature circuit imparts to the motor torque when the speed falls off, but at the same time the conditions are such that the motor comes out of synchronism more readily. To increase the tendency to synchronism, two circuits may be used on the armature, one of which is short circuited on the start, and both connected with the external circuit after the synchronous speed is reached or passed.

The method involved in this invention of operating a motor by producing artificially a difference of current phase in its independent energizing circuits, and the broad feature of a motor having energizing circuits of different self induction, are not claimed herein.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed as communicated to me by my foreign correspondent I declare that what I claim is :—

1. An alternating current motor having two or more energizing circuits, the coils of one circuit being composed of conductors of large size or low resistance, and those of the other of fewer turns of wire of smaller size or higher resistance, as set forth.

2. In an alternating current motor, the combination with long and short field cores, of energizing coils included in independent circuits, the coils on the longer cores containing an excess of copper or conductor over that in the others, as set forth.

3. The combination with a field magnet composed of magnetic plates having an open center and pole pieces or cores of different length, of coils surrounding said cores and included in independent circuits, the coils on the longer cores containing an excess of copper over that in the others, as set forth.

4. The combination with a field magnet composed of magnetic plates having an open center and pole pieces or cores of different length, of coils surrounding said cores and included in independent circuits, the coils on the longer cores containing an excess of copper over that in the others, and being set in recesses in the iron core formed by the plates, as set forth.

5. In an alternating current motor, the combination with field circuits of different self-inductive capacity of corresponding armature circuits electrically connected therewith, as set forth.

6. In an alternating current motor, the combination with independent field coils of different self-induction of independent armature coils, one or more in circuit with the field coils and the others short circuited, as set forth.

7. The method herein described of operating alternating current motors having independent energizing circuits, which consists in short circuiting the armature circuit or circuits until the motor has reached or passed a synchronizing speed and then connecting said armature circuits with the external circuit, as set forth.

8. The method of operating alternating current motors having field coils of different self-induction, which consists in directing alternating currents from an external source through the field circuits only until the motor has reached a given speed and then directing said currents through both the field circuits and one or more of the armature circuits, as set forth.

9. The method of operating alternating current motors having field coils of different self-induction, which consists in directing alternating currents from an external source through the field circuits and short circuiting a part of the armature circuits, and then when the motor has attained a given speed, directing the alternating currents through both the field and one or more of the armature circuits, as set forth.

Dated this 3rd day of December 1889.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, Agents for the Applicant.

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[G. 6914—125—11/1902.]

3rd Edition

Fig. 1

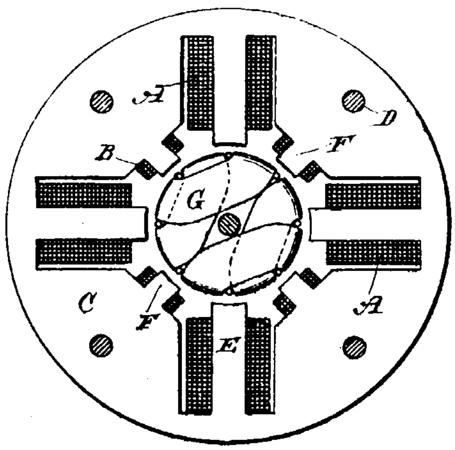


Fig. 2

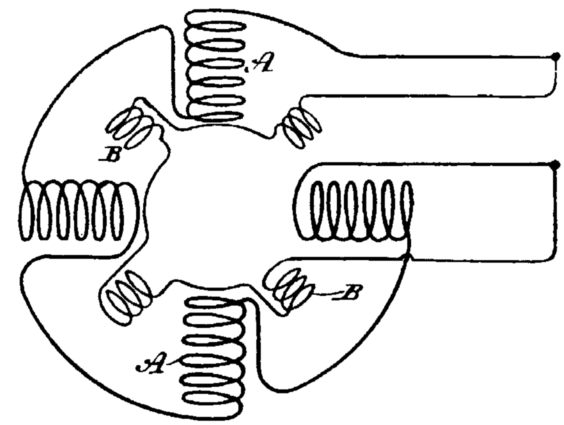


Fig. 3

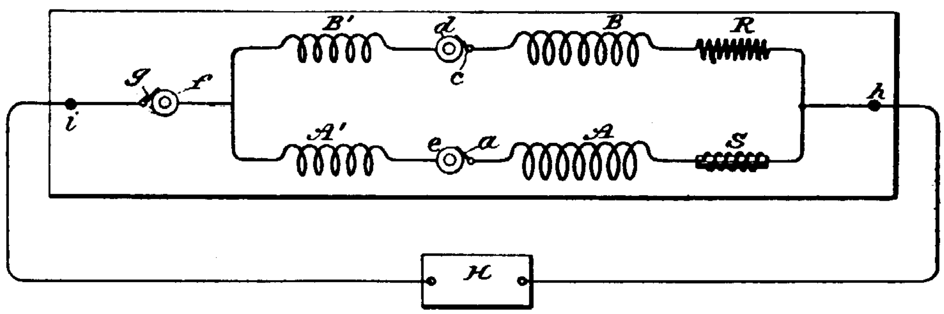


Fig. 4

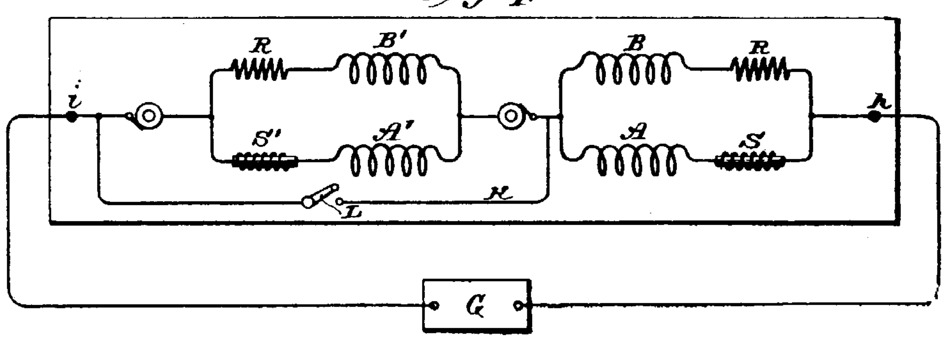
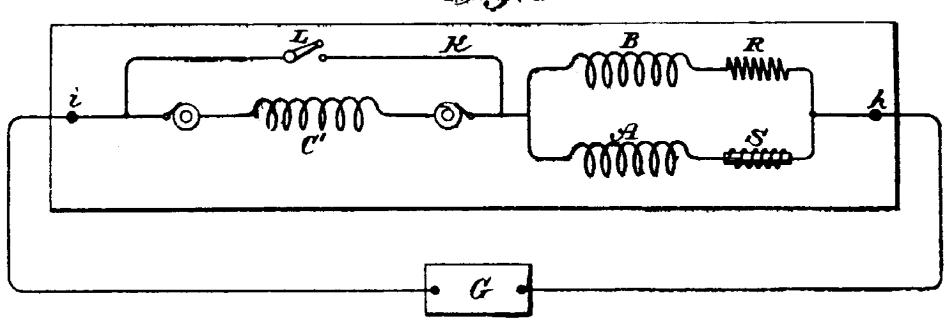


Fig. 5



[This Drawing is a reproduction of the Original on a reduced scale.]

N° 20,981 A.D. 1896

Date of Application, 22nd Sept., 1896—Accepted, 21st Nov., 1896

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of 46 East Houston Street, New York, United States of America, Electrician.]

Improvements relating to the Production, Regulation, and Utilization of Electric Currents of High Frequency, and to Apparatus therefor.

I, HENRY HARRIS LAKE, of the Firm of Haseltine, Lake & Co., Patent Agents, 45 Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention, subject of the present application, is embodied in certain improvements in methods of and apparatus for producing, regulating and utilizing electric currents of high frequency heretofore invented by Nikola Tesla, and described in British Letters Patent No. 8575, dated May 19, 1891. The method and apparatus referred to in said patent were devised for the purpose of converting, supplying and utilizing electrical energy in a form suited for the production of certain novel electrical phenomena which require currents of high potential and a higher frequency than can readily or even possibly, be developed by generators of the ordinary types or by such mechanical appliances as were theretofore known. The invention referred to was based upon the principle of charging a condenser or a circuit possessing capacity and discharging the same, generally through the primary of a transformer, the secondary of which constituted the source of working current, and under such conditions as to yield a vibratory or rapidly intermittent discharge current.

The present invention, while aiming to simplify and render more efficient the apparatus heretofore used, has for its object, primarily, to provide a means for converting such currents as are generally and most readily obtainable from the mains of ordinary systems of municipal distribution, into currents of the special character referred to, and to regulate or control, and utilize such currents in a simple, economical and efficient manner. The improvements are illustrated herein in forms of apparatus adapted for use with existing circuits or systems, and which while constructed and operating on the same general principles are modified only as may be required by a direct or an alternating source of supply.

The apparatus by which the present improvements are carried out may be described in general terms as comprising a circuit from a given source of supply, in which is included or with which is connected any suitable device for making and breaking such circuit in the manner desired, a condenser arranged so as to be periodically charged by the said circuit through the instrumentality of the circuit controller, and a circuit, through which the condenser discharges, of such character that the discharge will take place in a series of rapidly recurring or intermittent impulses.

In the drawings which illustrate the invention,

Fig. 1 is a diagram of circuits and apparatus employed with a source of direct currents. Figs. 2 and 3 are modifications of the same.

Figs. 4, 5 and 6 illustrate the apparatus and circuit connections employed with a source of alternating current. Figs. 7, 8, 9, 10 are similar views illustrating the method of and apparatus for regulating the system.

Figs. 11, 12, 13, 14 and 15 are views illustrating a form of circuit controller for use with the system and the manner of connecting up and using the same.

When the apparatus is to be employed for the purpose of converting a direct current of comparatively low potential into one of high frequency, a device in the nature of a choking coil is interposed in the circuit, in order that advantage may be taken of the discharge of high electro-motive force, which is manifested at each break of such circuit, for charging a condenser.

It will be apparent from a consideration of the conditions involved, that were the condenser to be directly charged by the current from the source and then discharged into its local or discharging circuit, a very large capacity would ordinarily be required, but by the introduction into the charging circuit of a high self induction the current of high electro-motive force which is induced at each break of said circuit, furnishes the proper current for charging the condenser, which may, therefore, be small and inexpensive.

Figures 1 and 2 illustrate that part of the improvement which relates to the conversion of direct or continuous current. Referring to said figures, A designates any source of direct current. In any branch of the circuit from said source, such, for example, as would be formed by the conductors A^{11} A^{11} from the mains A^1 A^1, and the conductors K K are placed self induction or choking coils B B and any proper form of circuit controlling device as C. This device in the present instance is shown as an ordinary metallic disk or cylinder with teeth or separated segments D D, E E, of which one or more pairs as E E, diametrically opposite, are integral or in electrical contact with the body of the cylinder, so that when the controller is in the position in which the two brushes F, F^1, bear upon two of said segments E E, the circuit through the choking coils B B will be closed. The segments D, D, are insulated, and while shown in the drawings as of substantially the same length of arc as the segments E E, this latter relation may be varied at will to regulate the periods of charging and discharging.

The controller is designed to be rotated by any proper device, such for example, as an electro-magnetic motor, as shown in Figure 2, receiving current either from the main source or elsewhere.

Around the controller C or in general having its terminals connected with the circuit on opposite sides of the point of interruption, is a condenser H, or a circuit of suitable capacity, and in series with the latter the primary K of a transformer, the secondary L of which constitutes the source of the currents of high frequency. L^1 indicates the circuit from the secondary and may be regarded as the working circuit.

It will be observed that since the self induction of the circuit through which the condenser discharges, as well as the capacity of the condenser itself, may be given practically any desired value, the frequency of the discharge current may be adjusted at will.

In the operation of this apparatus the controller closes the charging circuit and then interrupts the same. When the break occurs the accumulated energy in the said circuit charges the condenser. Then while the charging circuit is again completed the condenser discharges through the primary K, by a succession of rapid impulses. These operations are maintained by the action of the controller.

A more convenient and simplified arrangement of the apparatus is shown in Figure 2. In this case the small motor G which drives the controller has its field coils M M^1 in derivation to the main circuit, and the controller C and condenser H, are in parallel in the field circuit between the two coils. In such case the field coils M M^1 take the place of the choking coils B.

In this arrangement, and in fact, generally, it is preferable to use two condensers or a condenser in two parts, and to arrange the primary coil of the transformer between them. The interruption of the field circuit of the motor should be so rapid as to permit only a partial demagnetization of the cores; these latter, moreover, should in this specific arrangement, be laminated.

In lieu of connecting the field coils of the motor only with the charging circuit to raise the self induction therein, the motor may be connected in other ways, that is to say, its armature only may be connected with the circuit, or its field and armature coils may be in series and both connected with such circuit. This latter arrangement is illustrated in Figure 3, in which a terminal of the circuit A^{11} is connected to one of the binding posts of the motor from which the circuit is led through one field coil M, the brushes and commutator C^1 and the other field coil M^1, and thence to a brush F which rests upon the controller disk or cylinder C. The other terminal of the circuit connects with a second brush F^1 bearing on the controller, so that the current which passes through and operates the motor is periodically interrupted.

As an illustration of the various uses to which the apparatus may be put, the secondary L is shown in this figure as connected to two plates P, P, of any suitable character between which a current of air is maintained by a fan on the shaft of the motor G, for developing ozone or for similar purposes.

When the potential of the source of current periodically rises and falls, whether with reversals or not is immaterial, it is essential to economical operation that the intervals of interruption of the charging circuit should bear a definite time relation to the period of the current, in order that the effective potential of the impulses charging the condenser may be as high as possible. In case, therefore, an alternating or equivalent electromotive force be employed as the source of supply, a circuit controller is used which will interrupt the charging circuit at instants predetermined with reference to the variations of potential therein.

A convenient, and probably the most practicable means for accomplishing this is a synchronous motor connected with the source of supply and operating a circuit controller which first interrupts the charging current at or about the instant of highest intensity of each wave and then permits the condenser to discharge the energy stored in it, through its appropriate circuit. Such apparatus, which may be regarded as typical of the means for accomplishing this purpose, is illustrated in Figures 4, 5 and 6.

In Fig. 4, A^{11} A^{11} are the conductors taken from the mains of any alternating current generator A, and for raising the potential of such current a transformer is employed represented by the primary B and secondary B^1.

The circuit of the secondary includes the energizing coils of a synchronous motor G, and a circuit controller C fixed to the shaft of the motor.

An insulating arm O, stationary with respect to the motor shaft and adjustable with reference to the poles of the fixed magnets, carries two brushes F F^1 which bear upon the periphery of the disk C. With the parts thus arranged, the secondary circuit is completed through the coils of the motor whenever the two brushes rest upon the uninsulated segments of the disk, and interrupted through the motor at other times.

Such a motor, if properly constructed, in well understood ways, maintains very exact synchronism with the alternations of the source, and the arm O may, therefore, be adjusted to interrupt the current at any determined point of its waves. By the proper relations of insulated and conducting segments, and the motor poles, the current may be interrupted twice in each complete wave at or about the points of highest intensity.

In order that the energy stored in the motor circuit may be utilized at each break to charge the condenser H, the terminals of the latter are connected to the two brushes F F^1 or to points of the circuit adjacent thereto, so that when the circuit through the motor is interrupted the terminals of the motor circuit will be connected with the condenser. The discharge of the condenser takes place through the primary K, the circuit of which is completed simultaneously with the motor circuit and interrupted while the motor circuit is broken and the condenser being charged. The secondary impulses of high potential and great frequency are available for the operation of vacuum tubes P, single terminal lamps R, and other novel and useful purposes.

It is obvious that the supply current need not be alternating, provided it be converted or transformed into an alternating current, before reaching the controller. For example, the present improvements are applicable to various forms of rotary transformers as is illustrated in Figs. 5 and 6.

G^1 designates a continuous current motor, here represented as having four field poles wound with coils E^{11} in shunt to the armature. The line wires A^{11} A^{11} connect with the brushes *b b* bearing on the usual commutator.

On an extension of the motor shaft is a circuit controller composed of a cylinder, the surface of which is divided into four conducting segments *c*, and four insulating segments *d*, the former being diametrically connected in pairs as shown in Fig. 6.

Through the shaft run two insulated conductors *e e* from any two commutator segments ninety degrees apart, and these connect with the two pairs of segments *c*, respectively. With such arrangement, it is evident that any two adjacent segments *c c* become the terminals of an alternating current source, so that if two brushes F F^1 be applied to the periphery of the cylinder they will take off current during such portion of the wave as the width of segment and position of the brushes may determine. By adjusting the position of the brushes relatively to the cylinder, therefore, the alternating current delivered to the segments *c c* may be interrupted at any point of its waves.

While the brushes F F^1 are on the conducting segments the current which they collect stores energy in a circuit of high self-induction formed by the wires *f f*, self-induction coils S S, the conductors A^{11} A^{11}, the brushes and commutator. When this circuit is interrupted by the brushes F F^1, passing onto the insulating segments of the controller, the high potential discharge of this circuit stores energy in the condensers H H which then discharge through the circuit of low self-induction containing the primary K. The secondary circuit contains any devices as P, R, for utilizing the current.

In some cases the energy delivered by the system may be readily and economically regulated. It is well known that every electric circuit, provided its ohmic resistance does not exceed certain definite limits, has a period of vibration of its own analogous to the period of vibration of a weighted spring. In order to alternately charge a given circuit of this character by periodic impulses impressed upon it and to discharge it most effectively, the frequency of the impressed impulses should bear a definite relation to the frequency of vibration possessed by the circuit itself. Moreover, for like reasons, the period of vibration of the discharge circuit should bear a similar relation to the impressed impulses or the period of the charging circuit. When the conditions are such that the general law of harmonic vibrations is followed, the circuits are said to be in resonance or in electro-magnetic synchronism, and this condition of the system is found to be highly advantageous.

In carrying out the invention, therefore, the electrical constants should be so adjusted that in normal operation the condition of resonance is approximately attained. To accomplish this, the number of impulses of current directed into the charging circuit per unit time is made equal to the period of the charging circuit itself, or, generally, to a harmonic thereof, and the same relations are maintained between the charging and discharge circuit. Any departure from this condition will result in a decreased output, and this fact is taken advantage of in regulating such output by varying the frequencies of the impulses or vibrations in the several circuits.

Inasmuch as the period of any given circuit depends upon the relations of its resistance, self-induction and capacity, a variation of any one or more of these may result in a variation in its period. There are, therefore, various ways in which the frequencies of vibration of the several circuits in the system may be varied, but the most practicable and efficient ways of accomplishing the desired result are the following:

(*a*) Varying the rate of the impressed impulses or those which are directed from the source of supply into the charging circuit, as by varying the speed of the commutator or other circuit controller.

(*b*) Varying the self-induction of the charging circuit.

(*c*) Varying the self-induction or capacity of the discharge circuit.

To regulate the output of a single circuit which has no vibration of its own, by merely varying its period would evidently require, for any extended range of regulation, a very wide range of variation of period. But in the system described, a very wide range of regulation of the output may be obtained by a very slight change of the frequency of one of the circuits when the above mentioned rules are observed.

Figs. 7, 8, 9 and 10 illustrate some of the more practicable means for effecting the regulation, as applied to a system deriving its energy from a source of direct currents.

In each of the figures A^{11} A^{11} designate the conductors of a supply circuit of continuous current, G a motor connected therewith in any of the usual ways, and operating a current controller C which serves to alternately close the supply circuit through the motor or through a self-induction coil, and to connect such motor circuit with a condenser H, the circuit of which contains a primary coil K, in proximity to which is a secondary coil L serving as the source of supply to the working circuit or that in which are connected up the devices P R for utilizing the current.

In order to secure the greatest efficiency in a system of this kind, it is essential, as before stated, that the circuits, which mainly as a matter of convenience are designated as the charging and the discharge circuits, should be approximately in resonance or electro-magnetic synchronism. Moreover, in order to obtain the greatest output from a given apparatus of this kind it is desirable to maintain as high a frequency as possible.

The electrical conditions, which are now well understood, having been adjusted to secure, as far as practical considerations will permit, these results, the regulation of the system is effected by adjusting its elements so as to depart in a greater or less degree from the above conditions with a corresponding variation of output. For example, as in Figure 7 the speed of the motor, and consequently of the controller, may be varied in any suitable manner, as by means of a rheostat R^1 in a shunt to such motor, or by shifting the position of the brushes on the main commutator of the motor or otherwise. A very slight variation in this respect by disturbing the relations between the rate of impressed impulses and the vibration of the circuit of high self-induction into which they are directed, causes a marked departure from the condition of resonance and a corresponding reduction in the amount of energy delivered by the impressed impulses to the apparatus.

A similar result may be secured by modifying any of the constants of the local circuits as above indicated. For example, in Figure 8 the choking coil B is shown as provided with an adjustable core N^1, by the movement of which into and out of the coil the self-induction, and consequently the period of the circuit containing such coil, may be varied.

As an example of the way in which the discharge circuit or that into which the condenser discharges, may be modified to produce the same result, there is shown in Figure 9 an adjustable self-induction coil R^{11} in the circuit with the condenser, by the adjustment of which coil the period of vibration of such circuit may be changed.

The same result would be secured by varying the capacity of the condenser, but if the condenser were of relatively large capacity this might be an objectionable plan, and a more practicable method is to employ a variable condenser in the secondary or working circuit, as shown in Figure 10. As the potential in this circuit is raised to a high degree, a condenser of very small capacity may be employed, and if the two circuits, primary and secondary, are very intimately and closely connected, the variation of capacity in the secondary is similar in its effects to the variation of the capacity of the condenser in the primary. As a means well adapted for this purpose two metallic plates S^1 S^1 adjustable to and from each other and constituting the two armatures of the condenser are shown.

The description of the means of regulation is confined herein to a source of supply of direct current, for to such it more particularly applies, but it will be understood that if the system be supplied by periodic impulses from any source which will effect the same results, the regulation of the system may be effected by the method herein described.

The circuit controller or the device which ensures the proper charging and discharging of the condenser may be of any construction that will perform the functions required of it. In illustration of the principle of construction and mode of operation, reference has been made only to forms of mechanism that make and break metallic contacts, but there need be no actual metallic contact, if provision be made for the passage of a spark between separated conductors. Such a device is illustrated in Figs. 11 to 15.

A designates, in Fig. 11, a generator having a commutator a^1 and brushes a^{11} bearing thereon, and also collecting rings b^{11}, b^{11}, from which an alternating current is taken by brushes b^1 in the well understood manner.

The circuit controller is mounted, in part, on an extension of the shaft c^1 of the generator, and in part on the frame of the same, or on a stationary sleeve surrounding the shaft. Its construction, in detail, is as follows:—

e^1 is a metal plate with a central hub e^{11} which is keyed or clamped to the shaft c^1. The plate is formed with segmental extensions corresponding in number to the waves of current which the generator delivers. These segments are preferably cut away, leaving only rims or frames, to one of the radial sides of which are secured bent metal plates *i* which serve as vanes to maintain a circulation of air when the device is in operation.

The segmental disk and vanes are contained within a close insulated box or case *f* mounted on the bearing of the generator, or in any other proper way, but so as to be capable of angular adjustment around the shaft. To facilitate such adjustment, a screw rod f^1, provided with a knob or handle, is shown as passing through the wall of the box. The latter may be adjusted by this rod, and when in proper position may be held therein by screwing the rod down into a depression in the sleeve or bearing as shown in Fig. 11.

Air passages *g g* are provided at opposite ends of the box through which air is maintained in circulation by the action of the vanes.

Through the sides of the box *f*, and through insulating gaskets *h*, when the material of the box is not a sufficiently good insulator, extend metallic terminal plugs *l*, *l*, with their ends in the plane of the conducting segmental disk e^1 and adjustable radially towards and from the edges of the segments.

Devices of this character are employed in the manner illustrated in Fig. 13.

A, in this figure, represents any source of alternating current, the potential of which is raised by a transformer of which B is the primary and B^1 the secondary.

The ends of the secondary circuit *s* are connected to the terminal plugs *l*, *l*, of an apparatus similar to that of Figures 11 and 12, and having segments rotating in synchronism with the alternations of the current source, preferably, as above described, by being mounted on the shaft of the generator, when the conditions so permit.

The plugs *l*, *l*, are then adjusted radially so as to approach more or less the path of the outer edges of the segmental disk, and so that during the passage of each segment in front of a plug a spark will pass between them, which completes the secondary circuit, *s*. The box, or the support for the plugs *l*, is adjusted angularly so as to bring the plugs and segments into proximity at the desired instants with reference to any phase of the current wave in the secondary circuit, and fixed in position in any proper manner.

To the plugs *l*, *l*, are also connected the terminals of a condenser or condensers, so that at the instant of the rupture of the secondary circuit *s* by the cessation of the sparks the energy accumulated in such circuit will rush into, and charge, the condenser.

A path of low self-induction and resistance, including a primary K of a few turns, is provided to receive the discharge of the condenser, when the circuit *s* is again completed by the passage of sparks, the discharge being manifested as a succession of extremely rapid impulses.

By means of this apparatus effects of a novel and useful character are obtainable, but to still further increase the efficiency of the discharge or working current, there may be in some instances provided a means for further breaking up the individual sparks themselves. A device for this purpose is shown in Figures 14 and 15.

The box or case *f* in these figures is fixedly secured to the frame or bearing of the generator or motor which rotates the circuit controller in synchronism with the alternating source. Within said box is a disk e^1 fixed to the shaft c^1 with projections d^1 extending from its edge parallel with the axis of the shaft. A similar disk e^1 on a spindle d^{11} in face of the first is mounted in a bearing in the end of the box *f* with a capability of rotary adjustment.

The ends of the projections d^1 are deeply serrated or several pins or narrow projections placed side by side, as shown in Fig. 14, so that as those of the opposite disks pass each other a rapid succession of sparks will pass from the projections of one disk to those of the other.

The invention is not limited to the precise devices or forms of the devices shown and described. For example, when the source of supply is a circuit of high self-induction no special choking coils or the like need be employed. So, too, the condenser as a distinctive apparatus may be dispensed with when the capacity of its circuit is sufficiently great to accomplish the desired result. The circuit controller may, as already explained, be very greatly modified and varied in construction and principle of operation without departure from the invention.

In the illustrations given of the circuit controller, the contacts and insulating spaces are arranged for charging and discharging a single condenser, but it is obvious that a single motor and circuit controller may be used to operate more than one condenser, by charging one while discharging the other or others.

Having now particularly described and ascertained the nature of the said invention and in what manner the same is to be performed, as communicated to me by my foreign correspondent, I declare that what I claim is:—

1. The apparatus herein described for converting electric currents of the kind generally obtainable from municipal systems of electric distribution, into currents of high frequency, comprising in combination a circuit of high self-induction, a circuit controller adapted to make and break such circuit, a condenser into which the said circuit discharges when interrupted, and a transformer through the primary of which the condenser discharges, as set forth.

2. The combination with a circuit of high self-induction and means for making and breaking the same, of a condenser around the point of interruption in the said circuit, and a transformer the primary of which is in the condenser circuit, as described.

3. The combination with a circuit having a high self-induction, of a circuit controller for making and breaking said circuit, a motor for driving the controller, a condenser in a circuit connected with the first around the point of interruption therein, and a transformer the primary of which is in circuit with the condenser, as set forth.

4. The combination with an electric circuit of a controller for making and breaking the same, a motor included in or connected with said circuit so as to increase its self-induction and driving the said controller, a condenser in a circuit around the controller, and a transformer through the primary of which the condenser discharges, as set forth.

5. The combination with a circuit of direct current, of a controller for making and breaking the same, a motor having its field or armature coils or both included in said circuit and driving said controller, a condenser connected

with the circuit around the point of interruption therein, and a transformer, the primary of which is in the discharge circuit of the condenser, as set forth.

6. The method herein described of converting alternating currents of relatively low frequency into currents of high frequency, which consists in charging a condenser by such currents of low frequency during determinate intervals of each wave of said current, and discharging the condenser through a circuit of such character as to produce therein a rapid succession of impulses, as set forth.

7. The combination with a source of alternating current, a condenser, a circuit controller adapted to direct the current during determinate intervals of each wave into the condenser for charging the same, and a circuit into which the condenser discharges, as set forth.

8. The combination with a source of alternating current, a synchronous motor operated thereby, a circuit controller operated by the motor and adapted to interrupt the circuit through the motor at determinate points in each wave, a condenser connected with the motor circuit and adapted on the interruption of the same to receive the energy stored therein, and a circuit into which the condenser discharges, as set forth.

9. The combination with a source of alternating current, a charging circuit in which the energy of said current is stored, a circuit controller adapted to interrupt the charging circuit at determinate points in each wave, a condenser for receiving, on the interruption of the charging circuit, the energy accumulated therein, and a circuit into which the condenser discharges when connected therewith by the circuit controller, as set forth.

10. The method of regulating the energy delivered by a system for the production of high frequency currents, and comprising a supply circuit, a condenser, a circuit through which the same discharges, and means for controlling the charging of the condenser by the supply circuit and the discharging of the same, the said method consisting in varying the relations of the frequencies of the impulses in the circuits comprising the system, as set forth.

11. The method of regulating the energy delivered by a system for the production of high frequency currents comprising a supply circuit of direct currents, a condenser adapted to be charged by the supply circuit and to discharge through another circuit, the said method consisting in varying the frequency of the impulses of current from the supply circuit, as set forth.

12. The method of producing and regulating electric currents of high frequency which consists in directing impulses from a supply circuit into a charging circuit of high self-induction, charging a condenser by the accumulated energy of such charging circuit, discharging the condenser through a circuit of low self-induction, raising the potential of the condenser discharge and varying the relations of the frequencies of the electrical impulses in the said circuits, as set forth.

13. The combination with a source of current, of a condenser adapted to be charged thereby, a circuit into which the condenser discharges in a series of rapid impulses, and a circuit controller for effecting the charging and discharge of said condenser, composed of conductors movable into and out of proximity with each other, whereby a spark may be maintained between them and the circuit closed thereby during determined intervals, as set forth.

14. The combination with a source of alternating current, of a condenser adapted to be charged thereby, a circuit into which the condenser discharges in a series of rapid impulses, and a circuit controller for effecting the charging and discharge of said condenser composed of conductors movable into and out of proximity with each other in synchronism with the alternations of the source, as set forth.

15. A circuit controller for systems of the kind described, comprising in combination a pair of angularly adjustable terminals and two or more rotating conductors mounted to pass in proximity to the said terminals, as set forth.

16. A circuit controller for systems of the kind described, comprising in

combination two sets of conductors, one capable of rotation and the other of angular adjustment whereby they may be brought into and out of proximity to each other at determinate points and one or both being subdivided so as to present a group of conducting points, as set forth.

Dated this 22nd day of September 1896.

HASELTINE, LAKE & Co.,
45 Southampton Buildings, London, W.C., Agents for the Applicant.

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B

Fig. 1

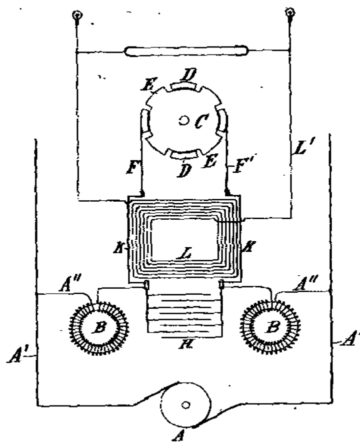

Fig. 2

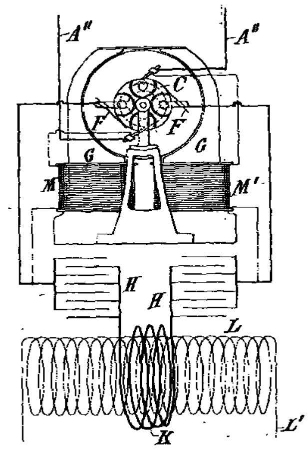

Fig. 3

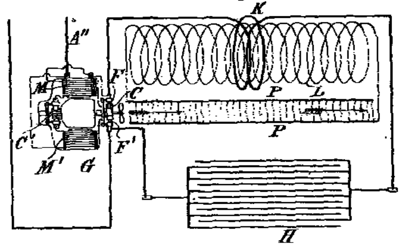

Fig. 9

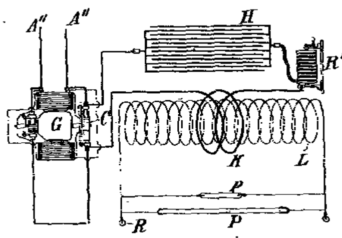

Fig. 7

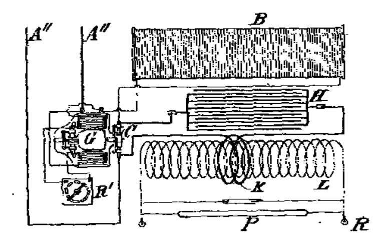

Fig. 8

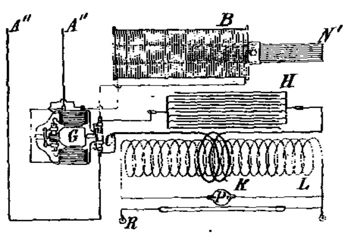

Fig. 10

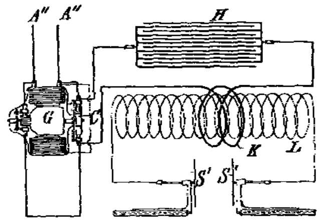

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Fig. 1

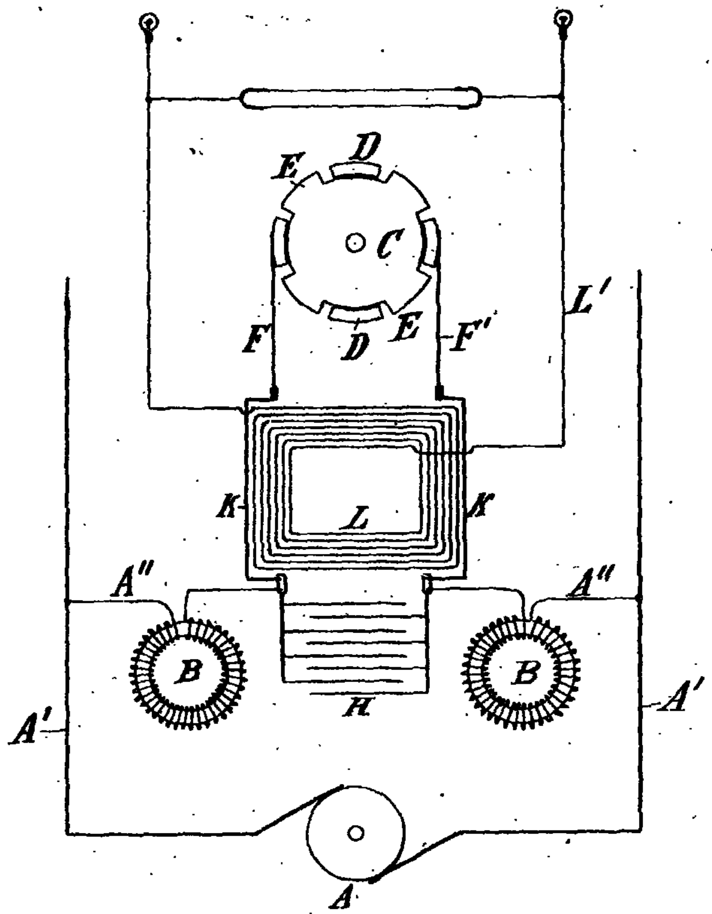


Fig. 2

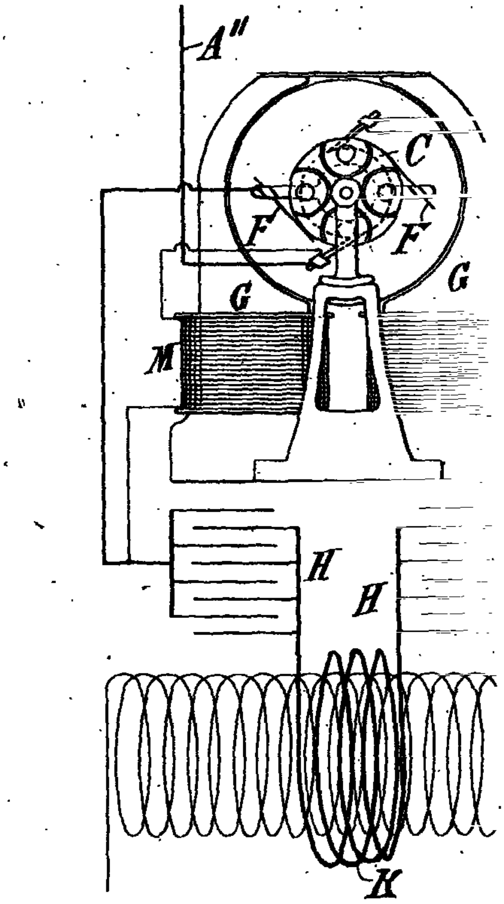


Fig. 7

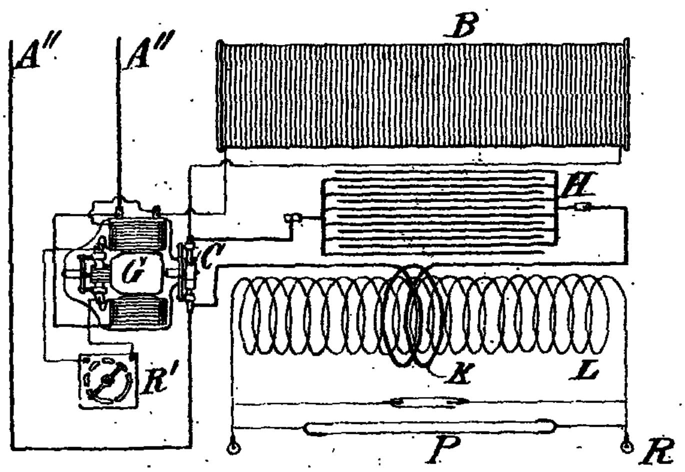
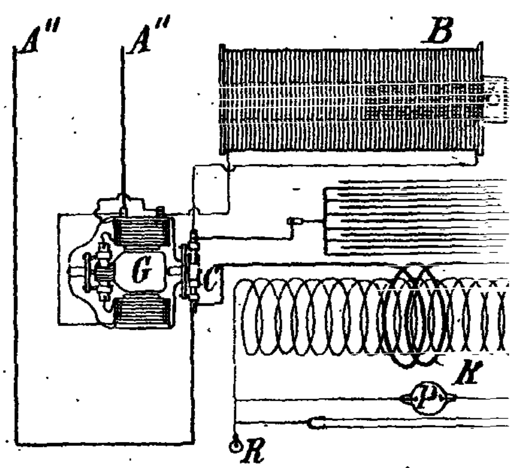


Fig. 8



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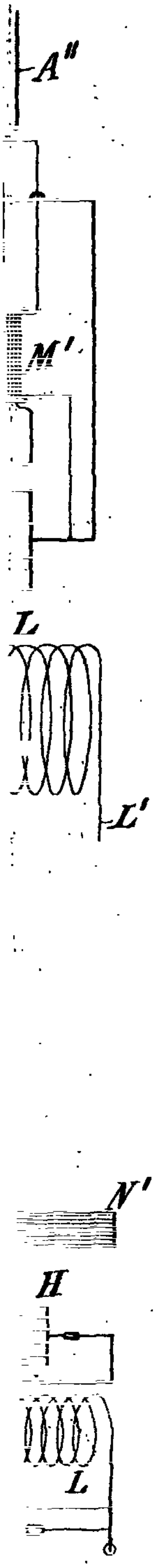

Fig. 3

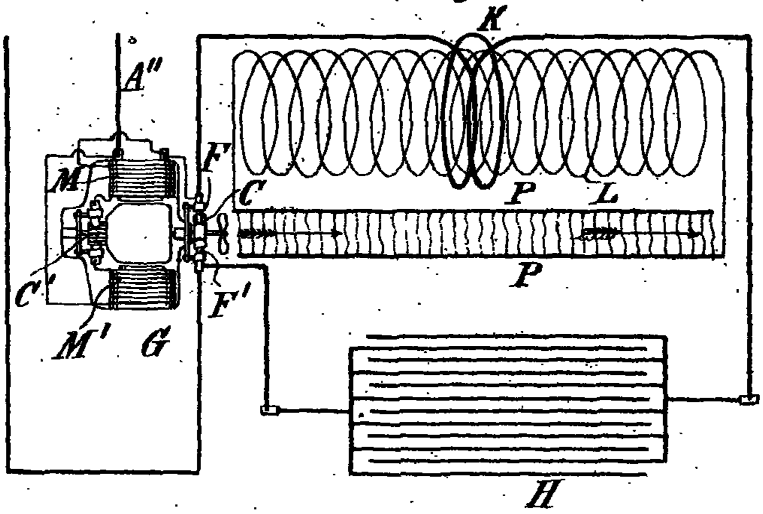

Fig. 9

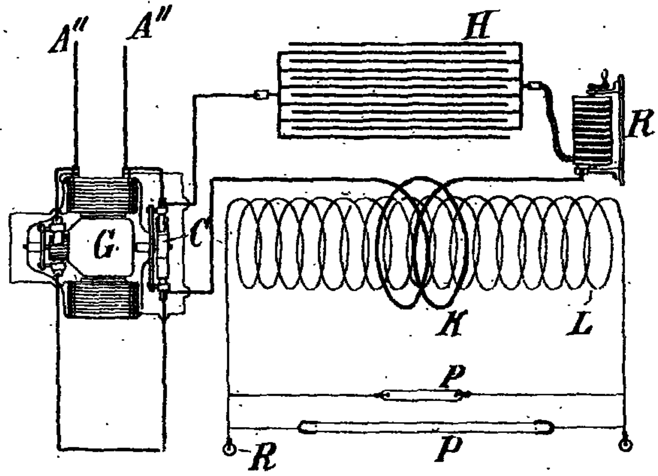

Fig. 10

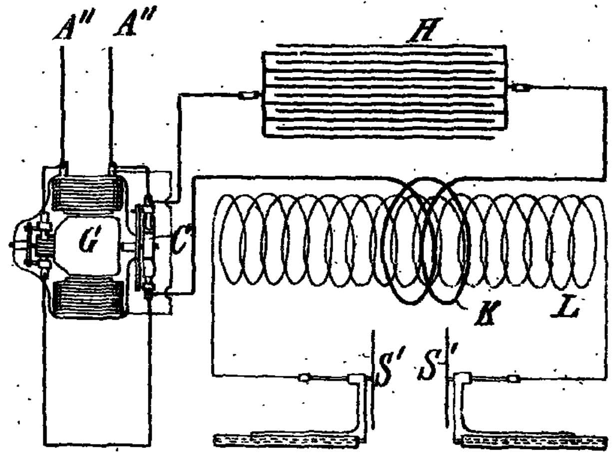

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Fig. 4

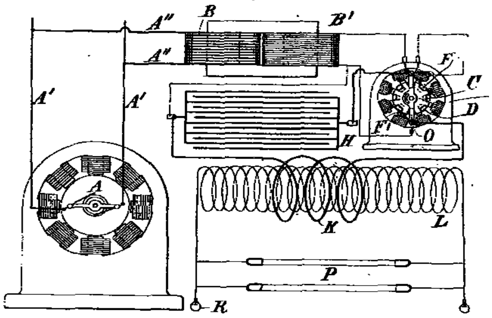

Fig. 5

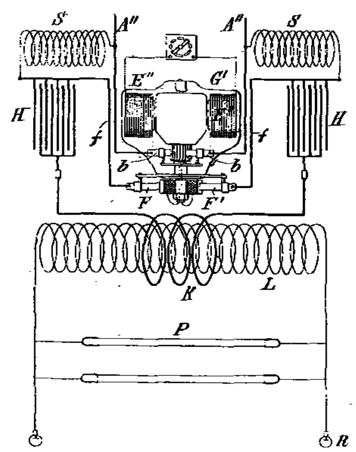

Fig. 6

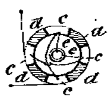

Fig. 11

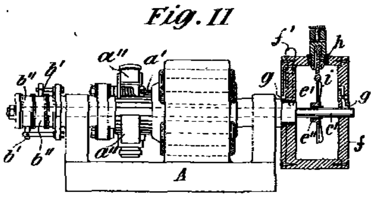

Fig. 12

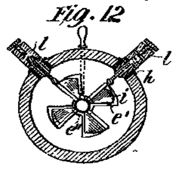

Fig. 13

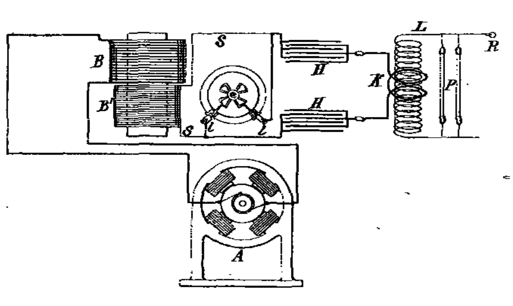

Fig. 14

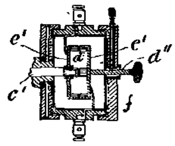

Fig. 15

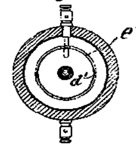

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Fig. 4

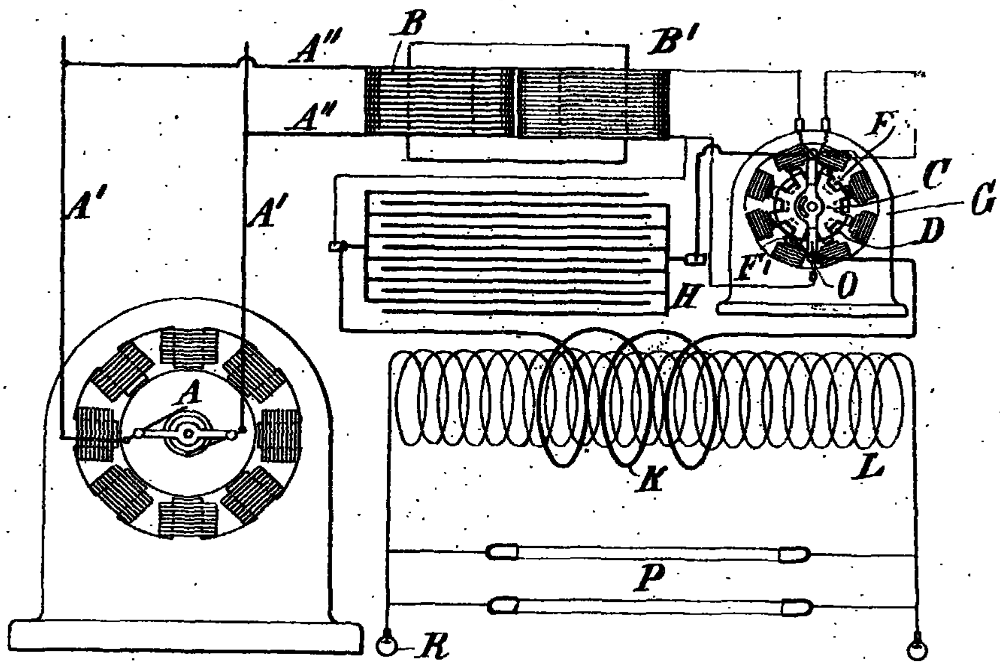


Fig.

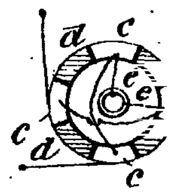


Fig. 11

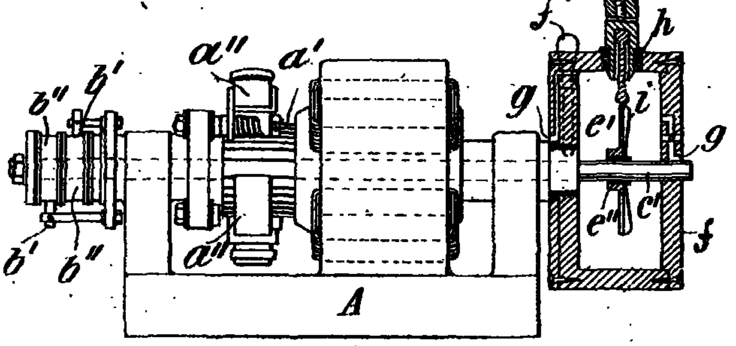


Fig. 12

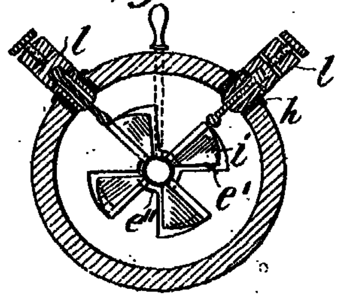


Fig. 14

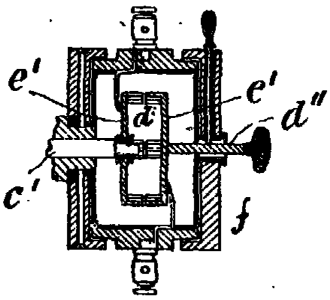
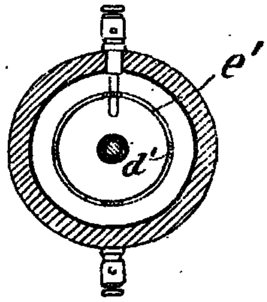


Fig. 15



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SHEET 2.

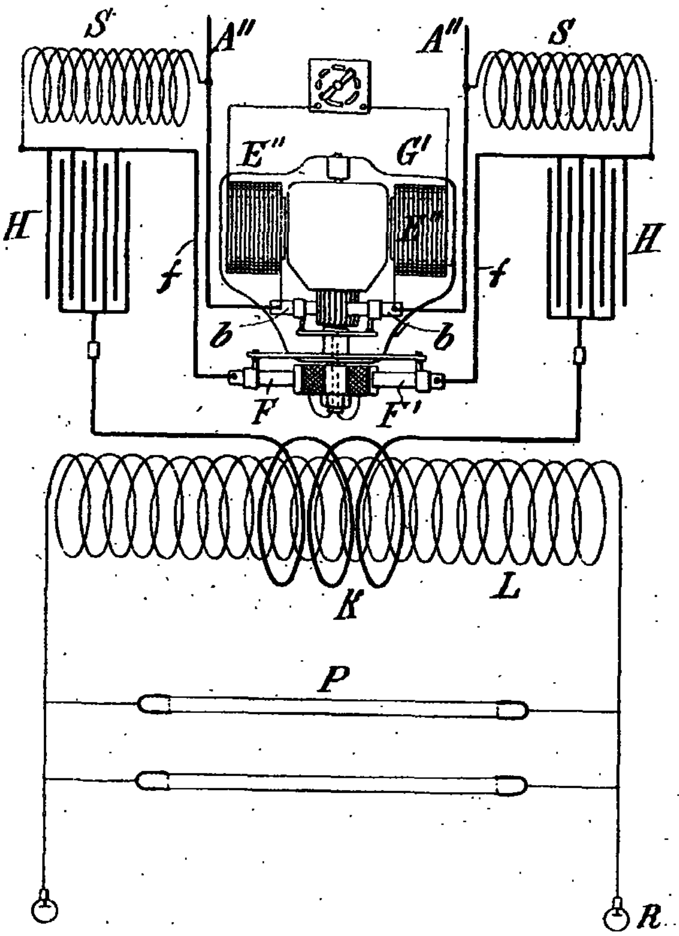

Fig. 5

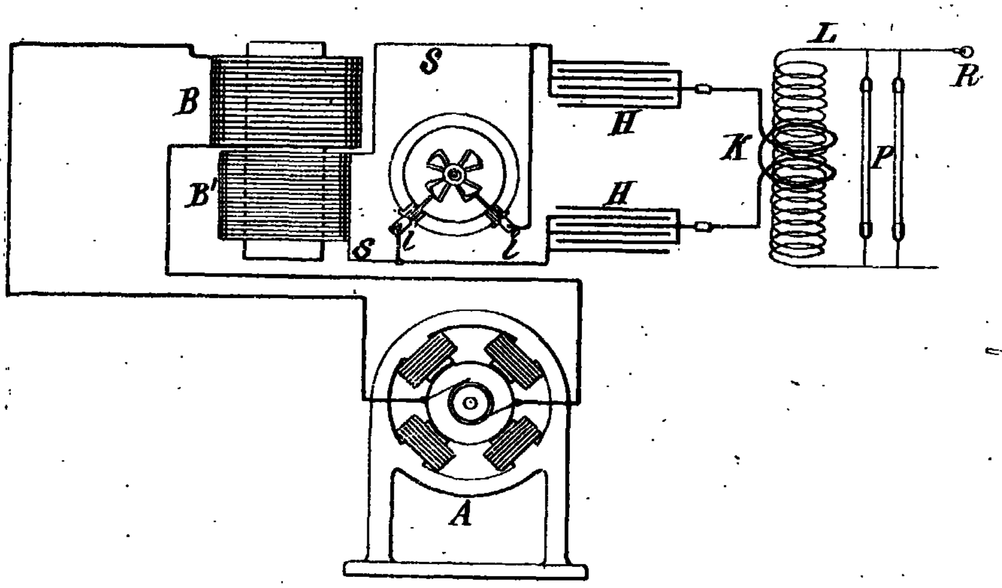

Fig. 13

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N° 24,001 A.D. 1910

(*Under International Convention.*)

Date claimed for Patent under Patents and Designs Act, 1907, being date of first Foreign Application (in the United States), } *21st Oct., 1909*

Date of Application (in the United Kingdom), 17th Oct., 1910

At the expiration of twelve months from the date of the first Foreign Application, the provision of Section 91 (3) (a) of the Patents and Designs Act, 1907, as to inspection of Specification, became operative

Accepted, 6th July, 1911

COMPLETE SPECIFICATION.

Improved Method of Imparting Energy to or Deriving Energy from a Fluid and Apparatus for use therein.

I, NIKOLA TESLA, Engineer, residing at the Waldorf-Astoria, corner 34th Street and Fifth Avenue, Borough of Manhattan, City and State of New York, U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In the practical application of mechanical power based on the use of a fluid as vehicle of energy it has been demonstrated that, in order to attain the highest economy, the changes in velocity and direction of movement of the fluid should be as gradual as possible. In the present known forms of such apparatus the fluid has always been guided or restrained more or less gradually but nevertheless restrained in its actual direction of flow, so that it followed some previously determined path. Attempts have been made to minimise shock as much as possible but no one seems to have conceived the idea of allowing the fluid to follow on entirely unrestrained path in its direction of motion so that shocks and vibrations and friction losses were unavoidable. Besides, the employment of the usual devices for imparting energy to, or deriving energy from a fluid, as pistons, paddles, vanes and blades, necessarily introduces numerous defects and limitations and adds to the complication, cost of production and maintenance of the machines.

The object of my invention is to overcome these deficiencies and to effect the transmission and transformation of mechanical energy through the agency of fluids in a more perfect manner, and by means simpler and more economical than those heretofore employed.

I accomplish this by allowing the propelled or propelling fluid to move in natural paths or stream lines of least resistance which are not determined by guiding or retaining surfaces such as vanes or kindred devices, interposed in the path of motion of the fluid and to change its velocity and direction of movement by imperceptible degrees, thus avoiding the losses due to sudden variations while the fluid is receiving or imparting energy. The only artificial restraint I propose to place on the fluid is restraint in a direction at right angles or substantially at right angles to its direction of motion.

It is well known that a fluid possesses, among others, two salient properties;

[*Price 8d.*]

adhesion and viscosity. Owing to these a body propelled through such a medium encounters a peculiar impediment known as "lateral" or "skin resistance" which is two-fold; one arising from the shock of the fluid against the asperities of this solid substance, the other from internal forces opposing molecular separation. As an inevitable consequence a certain amount of the fluid is dragged along by the moving body. Conversely, if the body be placed in a fluid in motion, for the same reasons, it is impelled in the direction of movement.

These effects, in themselves, are of daily observation, but I believe that I am the first to apply them in a practical and economical manner of fluid propulsion. The nature of my discovery and the principles of construction of the apparatus which I have designed for carrying it out, I shall now proceed to describe by reference to the accompanying drawings which illustrate an operative and efficient embodiment of the same.

Fig. 1 is a partial end view, and Fig. 2 a vertical cross section of a pump or compressor, which Figs. 3 and 4 represent, respectively, in corresponding views, a rotary engine or turbine, both machines being constructed and adapted to be operated in accordance with my invention.

Figs. 1 and 2 show a runner composed of a plurality of flat rigid disks 1 of a suitable diameter, keyed to a shaft 2 and held in position by a threaded nut 3, a shoulder 4 and washers 5 of the requisite thickness. Each dish has a number of central openings 6, the solid portions between which form spokes 7 preferably curved, as shown, for the purpose of reducing the loss of energy due to the impact of the fluid.

This runner is mounted in a two-part volute casing 8 having stuffing boxes 9 and inlets 10 leading to its central portion. In addition a gradually widening and rounding outlet 11 is provided formed with a flange for connection to a pipe as usual. The casing 8 rests upon a base 12 shown only in part and supporting the bearings for the shaft 2, which being of ordinary construction are omitted from the drawings.

An understanding of the principle embodied in this device will be gained from the following description of its mode of operation.

Power being applied to the shaft and runner set in rotation in the direction of the solid arrow, the fluid by reason of its properties of adherence and viscosity, upon entering through the inlets 10 and coming in contact with the disks 1 is taken hold of by the same and subjected to two forces, one acting tangentially in the direction of rotation, and the other radially outward. The combined effect of these tangential and centrifugal forces is to propel the fluid with continuously increasing velocity in a spiral path until it reaches the outlet 11 from which it is ejected. This spiral movement, free and undisturbed and essentially dependent on these properties of the fluid, permitting it to adjust itself to natural paths or stream lines and to change its velocity and direction by insensible degrees, is characteristic of this method of propulsion and advantageous in its application.

While traversing the chamber enclosing the runner, the particles of the fluid may complete one or more turns, or but a part of one turn. In any given case their path can be closely calculated and graphically represented, but fairly accurate estimates of turns can be obtained simply by determining the number of revolutions required to renew the fluid passing through the chamber and multiplying it by the ratio between the mean speed of the fluid and that of the disks.

I have found that the quantity of fluid propelled in this manner is, other conditions being equal, approximately proportionate to the active surface of the runner and to its effective speed. For this reason, the performance of such machines augments at an exceedingly high rate with the increase of their size and speed of revolution.

The dimensions of the device as a whole, and the spacing of the disks in any given machine will be determined by the conditions and requirements of special cases. It may be stated that the intervening distance should be the greater, the larger the diameter of the disks, the longer the spiral path of the fluid and the greater its viscosity. In general, the spacing should be such that the entire mass of the fluid, before leaving the runner, is accelerated to a nearly uniform velocity, not much below that of the periphery of the disks under normal working conditions and almost equal to it when the outlet is closed and the particles moved in concentric circles.

It may also be pointed out that such a pump can be made without openings and spokes in the runner, as by using one or more solid disks, each in its own casing, in which form the machine will be eminently adapted for sewage, dredging and the like, when the water is charged with foreign bodies and spokes or vanes especially objectionable.

Another application of this principle which I have discovered to be not only feasible, but thoroughly practicable and efficient, is the utilization of machines such as above described for the compression or rarefaction of air, or gases in general. In such cases it will be found that most of the general considerations obtaining in the case of liquids, properly interpreted, hold true.

When, irrespective of the character of the fluid, considerable pressures are desired, staging or compounding may be resorted to in the usual way the individual runners being, preferably, mounted on the same shaft.

The principles underlying the invention are capable of embodiment also in that field of mechanical engineering which is concerned in the use of fluids as motive agents, for while in some respects the actions in the latter case are directly opposite to those met with in the propulsion of fluids, the fundamental laws applicable in the two cases are the same. In other words, the operation above described is reversible, for if water or air be admitted under pressure to the opening 11 the runner is set in rotation in the direction of the dotted arrow by reason of the peculiar properties of the fluid which, travelling in a spiral path and with continuously diminishing velocity, reaches the orifices 6 and 10 through which it is discharged. If the runner be allowed to turn freely, in nearly frictionless bearings, its rim will attain a speed closely approximating the maximum of that of the fluid in the volute channel and the spiral path of the particles will be comparatively long, consisting of many almost circular turns. If load is put on and the runner slowed down, the motion of the fluid is retarded, the turns are reduced, and the path is shortened.

Owing to a number of causes affecting the performance it is difficult to frame a precise rule which would be generally applicable, but it may be stated that within certain limits, and other conditions being the same, the torque is directly proportionate to the square of the velocity of the fluid relatively to the runner and to the effective area of the disks and, inversely, to the distance separating them. The machine will, generally, perform its maximum work when the effective speed of the runner is one half of that of the fluid. But to attain the highest economy the relative speed or slip, for any given performance, should be as small as possible. This condition may be to any desired degree approximated by increasing the active area and reducing the space between the disks.

When apparatus of the kind described is employed for the transmission of power certain departures from similarity between transmitter and receiver may be necessary for securing the best results. It is evident that, when transmitting power from one shaft to another by such machines, any desired ratio between the speeds of rotation may be obtained by proper selection of the diameters of the disks, or by suitably staging the transmitter, the receiver, or both. But it may be pointed out that in one respect, at least, the two machines are essentially different. In the pump, the radial or static pressure, due to centrifugal force, is added to the tangential or dynamic, thus increasing the effective head and assisting in the expulsion of the fluid. In the motor, on the contrary, the first named pressure, being opposed to that of supply, reduces the effective head and the velocity of radial flow towards the center. Again, in the propelled machine a great torque is always desirable, this calling for an increased number of disks and smaller distance of separation, while in the propelling machine, for numerous economic reasons, the rotary effect should be the smallest and the speed the greatest practicable. Many other considerations, which will naturally suggest themselves, may affect the design and construction, but the preceding is thought to contain all necessary information in this regard.

The greatest value of this invention will be found in its use for the thermo-dynamic conversion of energy. Reference is now made to Figs. 3 and 4, illustrative of the manner in which it is, or may be, so applied.

As in the previous figures, a runner is provided made up of disks 13 with openings 14 and spokes 15 which, in this case may be straight. The disks are keyed to and held in position on a shaft 16, mounted to turn freely in suitable bearings, not shown, and are separated by washers 17 conforming in shape with the spokes and firmly united thereto by rivets 18. For the sake of clearness but a few disks, with comparatively wide intervening spaces, are indicated.

The runner is mounted in a casing comprising two end castings 19 with outlets 20 and stuffing boxes 21, and a central ring 22, which is bored out to a circle of a diameter slightly larger than that of the disks, and has flanged extensions 23 and inlets 24 into which finished ports, or nozzles, 25 are inserted. Circular grooves 26 and labyrinth packings 27 are provided on the sides of the runner. Supply pipes 28, with valves 29, are connected to the flanged extensions of the central ring one of the valves being, normally, closed.

With the exception of certain particulars, which will be hereinafter elucidated, the mode of operation will be understood from the preceding description. Steam or gas under pressure being allowed to pass through the valve at the side of the solid arrow, the runner is set in rotation in clockwise direction.

In order to bring out a distinctive feature assume, in the first place, that the motive medium is admitted to the disk chamber through a port, that is, a channel which it traverses with nearly uniform velocity. In this case, the machine will operate as a rotary engine, the fluid continuously expanding on its tortuous path to the central outlet. The expansion takes place chiefly along the spiral path, for the spread inward is opposed by the centrifugal force due to the velocity of whirl and by the great resistance to radial exhaust. It is to be observed that the resistance to the passage of the fluid between the plates is, approximately proportionate to the square of the relative speed, which is maximum in the direction towards the center and equal to the full tangential velocity of the fluid. The path of least resistance, necessarily taken in obedience to a universal law of motion is, virtually, also that of least relative velocity.

Next, assume that the fluid is admitted to the disk chamber not through a port, but a diverging nozzle, a device converting wholly or in part, the expansive into velocity-energy. The machine will then act rather like a turbine, absorbing the energy of kinetic momentum of the particles as they whirl, with continuously decreasing speed, to the exhaust.

The above description of the operation, I may add, is suggested by experience and observation, and is advanced merely for the purpose of explanation. The undeniable fact is that the machine does operate, both expansively and impulsively. When the expansion in the nozzle is complete, or nearly so, the fluid pressure in the peripheral clearance space is small; as the nozzle is made less divergent and its section enlarged, the pressure rises, finally approximating that of the supply. But the transition from purely impulsive to expansive action may not be continuous throughout, on account of critical states and conditions and comparatively great variations of pressure may be caused by small changes of nozzle velocity.

In the preceding it has been assumed that the pressure of supply is constant or continuous, but it will be understood that the operation will be, essentially, the same if the pressure be fluctuating or intermittent, as that due to explosions occurring in more or less rapid succession.

A very desirable feature, characteristic of machines constructed and operated in accordance with this invention, is their capability of reversal of rotation. Fig. 3, while illustrative of a special case, may be regarded as typical in this respect. If the right hand valve be shut off and the fluid supplied through the second pipe, the runner is rotated in the direction of the dotted arrow the operation, and also the performance, remaining the same as before, the central ring being bored to a circle with this purpose in view. The same result may be obtained in many other ways by specially designed valves, ports or nozzles for reversing the flow, the description of which is omitted here in the interest of simplicity and clearness. For the same reasons but one operative port or nozzle is illustrated which might be adapted to a volute but does not fit best a circular bore. It will be understood that a number of suitable inlets may be provided around the periphery of the runner to improve the action and that the construction of the machine may be modified in any ways.

Still another valuable and probably unique quality of such motors or prime movers may be described. By proper construction and observance of working conditions the centrifugal pressure, opposing the passage of the fluid, may, as already indicated, be made nearly equal to the pressure of supply when the machine is running idle. If the inlet section be large, small changes in the speed of revolution will produce great differences of flow which are further enhanced by the concommittant variations in the length of the spiral path. A self-regulating machine is thus obtained bearing a striking resemblance to a direct current electric motor in this respect that, with great differences of impressed pressure in a wide open channel the flow of the fluid through the same is prevented by virtue of rotation. Since the centrifugal head increases as the square of the revolutions, or even more rapidly, and with modern high grade steel great peripheral velocities are practicable, it is possible to attain that condition in a single stage machine, more readily if the runner be of large diameter. Obviously this problem is facilitated by compounding, as will be understood by those skilled in the art. Irrespective of its bearing on economy, this tendency, which is, to a degree, common to motors of the above description, is of special advantage in the operation of large units, as it affords a safeguard against running away and destruction.

Besides these, such a prime mover possesses many other advantages, both constructive and operative. It is simple, light and compact, subject to but little wear, cheap and exceptionally easy to manufacture as small clearances and accurate milling work are not essential to good performance. In operation it is reliable, there being no valves, sliding contacts or troublesome vanes. It is almost free of windage, largely dependent of nozzle efficiency and suitable for high as well as for low fluid velocities and speeds of revolution.

It will be understood that the principles of construction and operation above generally set forth, are capable of embodiment in machines of the most widely different forms, and adapted for the greatest variety of purposes. In my present application I have sought to describe and explain only the general and typical applications of the principle which I believe I am the first to realize and turn to useful account.

I am aware that it has already been proposed to effect atomising by dropping a liquid on to a plate rotating about a substantially vertical axis and I make no claim to the arrangement.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The method of imparting energy to, or deriving it from a fluid consisting in bringing the fluid in contact with rotary surfaces where, by its natural properties of adhesion and viscosity, it is, under the action of tangential and radial

forces, free to follow its natural curved path, either radially outwards to the periphery or radially inwards to the axis of the rotating surfaces.

2. Apparatus for carrying out the method claimed in Claim 1, having one or several rotary discs mounted in a casing to which fluid is admitted centrally and allowed to follow its natural curved or spiral path between the separate discs or between the discs and casing consequent upon the radial and tangential forces acting thereon, said fluid being then allowed to pass off from an opening or passage leading from the periphery of the casing, substantially as set forth.

3. Apparatus for carrying out the process claimed in Claim 1, having one or several rotary discs mounted in a casing to which fluid is admitted circumferentially and substantially tangentially to the motion of the discs, said fluid being allowed under all conditions of loading to follow its natural curved or spiral path between the discs and casing consequent upon the radial and tangential forces reacting thereon and being subsequently withdrawn or exhausted substantially centrally.

4. Apparatus as claimed in Claim 3, characterised by nozzles for transforming the pressure energy of the fluid into velocity energy prior to its passing into contact with the discs, whereupon the velocity of the fluid is reduced gradually as it proceeds in its curved or substantially spiral path.

5. Apparatus as claimed in Claims 3 or 4, having two sets of nozzles or members for directing the stream of fluid on the rotary members, said sets being arranged to produce rotation in opposite directions and means for making one or other of said sets operative as desired, substantially as described.

6. The improved method of extracting energy from fluids or imparting energy thereto hereinbefore described and the apparatus for carrying out said method as hereinbefore described or illustrated in the accompanying drawings.

Dated this 17th day of October, 1910.

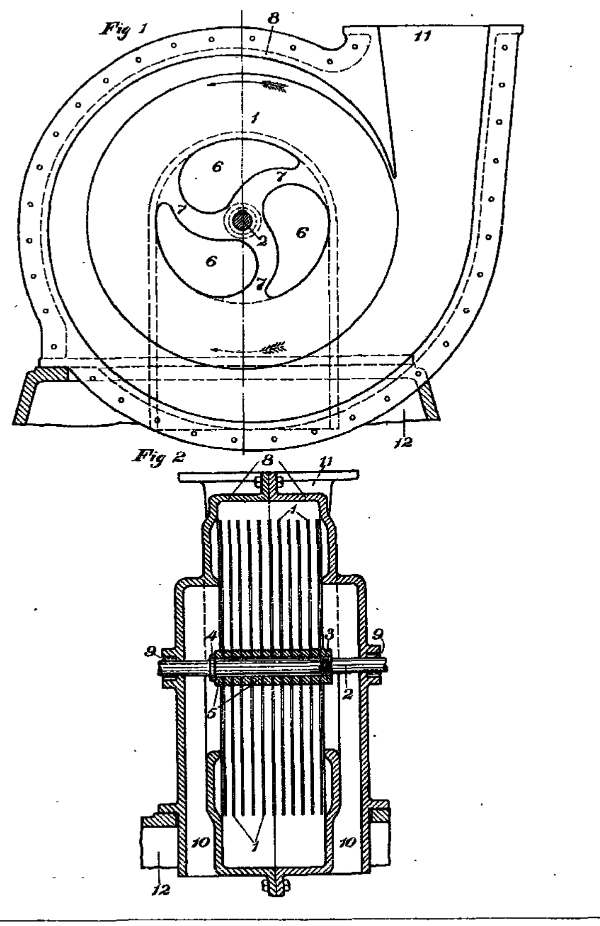
HY. FAIRBROTHER,
Agent for Applicant,
33, Cannon Street, London.

Reference has been directed in pursuance of Section 7, Sub-section 4, of the Patents and Designs Act, 1907, to Specification No. 696 of 1867.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1911.

(2 SHEETS)

SHEET 1.



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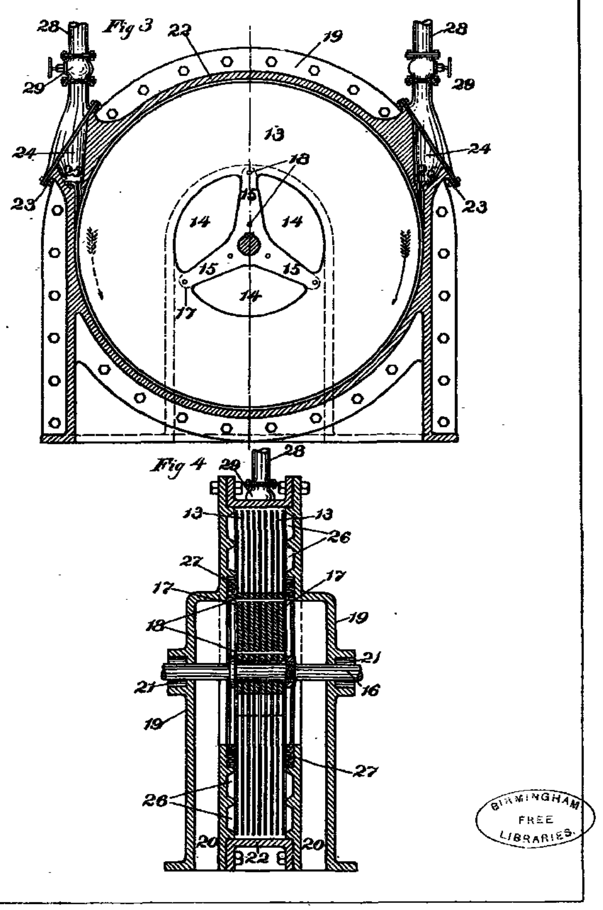

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SHEET 1.

Fig 1

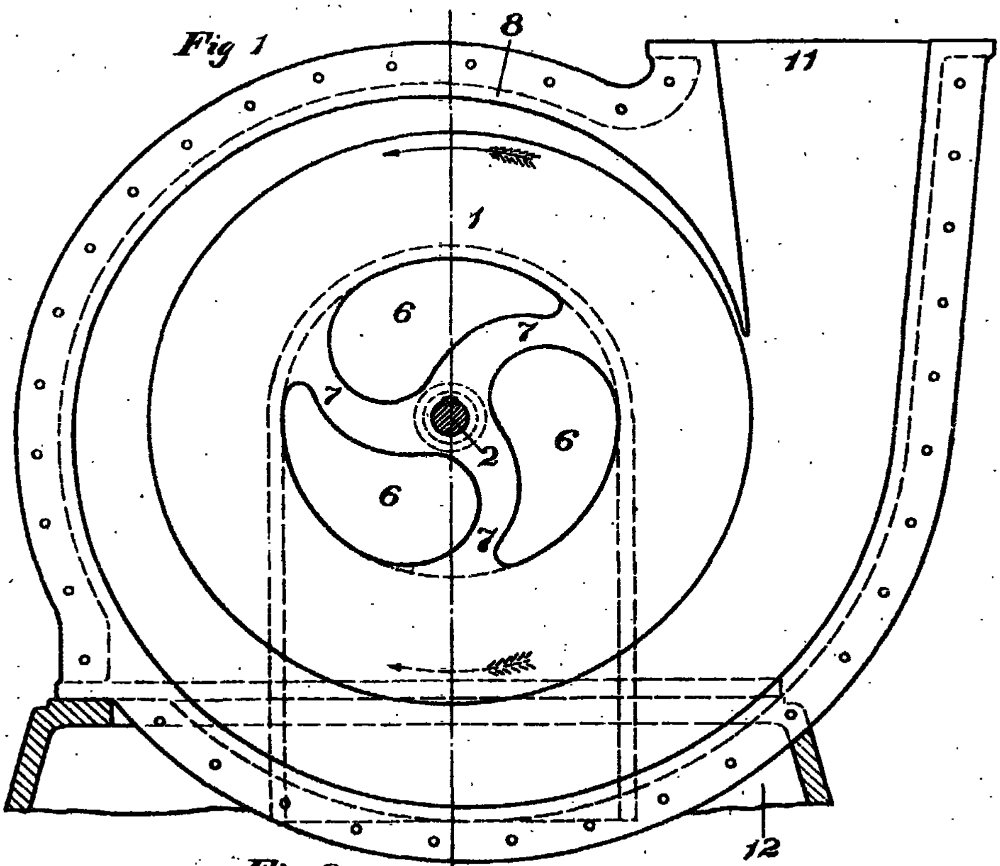

Fig 2

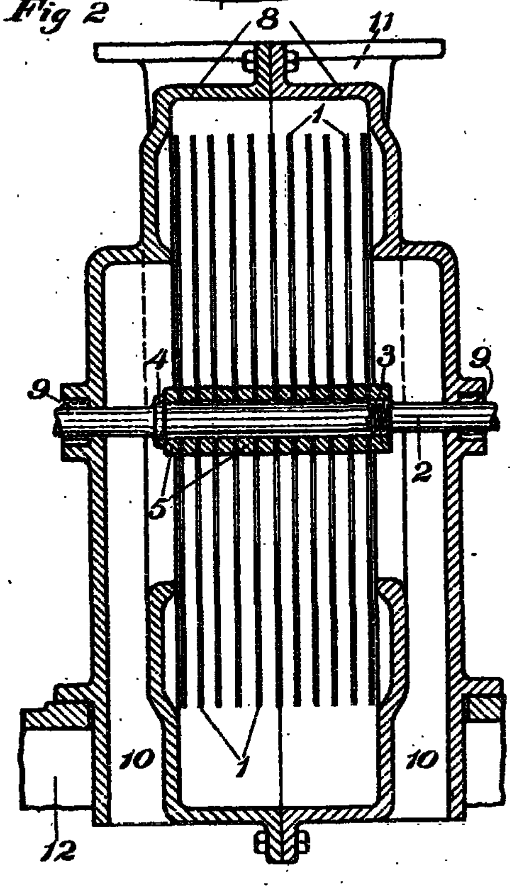

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Fig 3

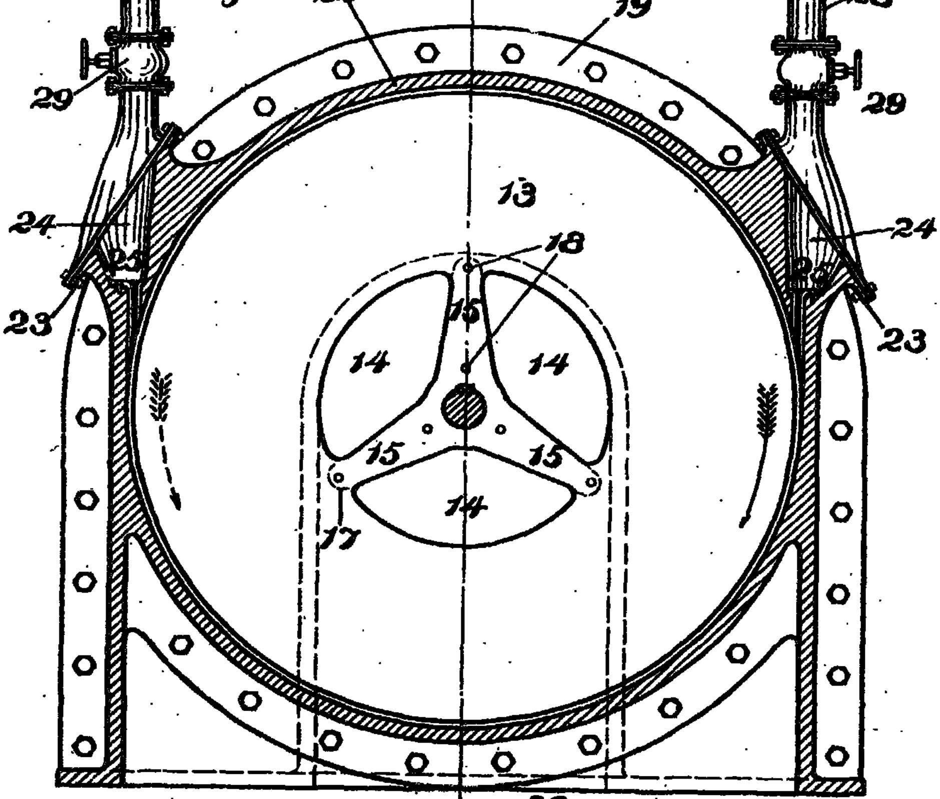
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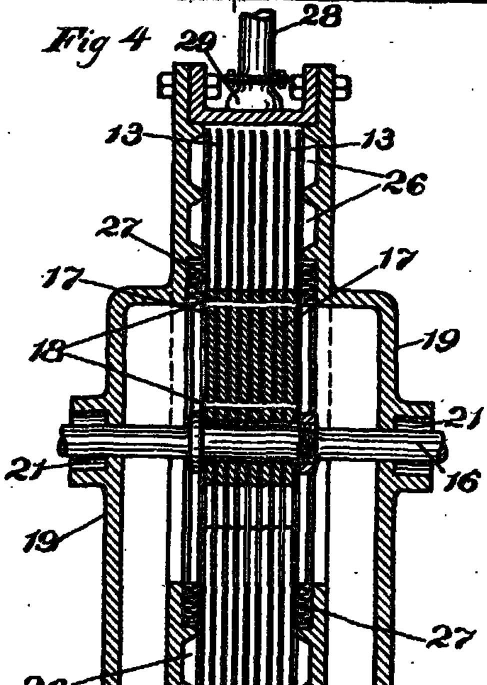
Fig 4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N° 24,421 A.D. 1897

Date of Application, 21st Oct., 1897—Accepted, 26th Mar., 1898

COMPLETE SPECIFICATION.

[Communicated from abroad by NIKOLA TESLA, of New York, in the County and State of New York, United States of America, Electrician.]

Improvements in Systems for the Transmission of Electrical Energy and Apparatus for use therein.

I, HENRY HARRIS LAKE, of the Firm of Haseltine, Lake & Co., Patent Agents, 45, Southampton Buildings, in the County of Middlesex, do hereby declare the nature of this invention, and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

It has been well known, hertofore, that if the air enclosed in a vessel be rarefied, its insulating properties are impaired to such extent that it becomes what may be considered as a true conductor of electricity, although one of admittedly high resistance. The practical information in this matter, however, has been derived from observations manifestly subject to limitations imposed by the character of the apparatus or means heretofore known, and the quality of the electrical effects producible thereby.

It has also been known, particularly since the investigations of Heinrich Herz, that certain transverse electrical waves or radiations may be transmitted through the atmosphere, and these have been found capable of affecting certain delicate receiving instruments at a limited distance from the source of the electrical disturbance.

The invention which forms the subject of the present application comprises a novel method or system for the transmission of electrical energy without the employment of metallic line conductors, and is primarily designed for use in cases where large amounts of electrical energy are to be transmitted to considerable distances, but the results arrived at are of such character and magnitude, as compared with any heretofore secured, as to render indispensable the employment of means and the utilization of effects essentially different in their characteristics and actions from those before used or investigated.

To be more explicit, the transmission of electrical energy, which forms a part of my present invention, demands for the attainment of practically useful results, the production and conversion of excessively high electrical pressures. Heretofore, it has been possible, by means of the apparatus at command, to produce only moderate effective electrical pressures, and even these not without some risks and difficulties, but I have devised means whereby I am enabled to generate with safety and ease electrical pressures measured by hundreds of thousands, and even millions, of volts, and in pursuing investigations with such apparatus I have discovered certain highly important and useful facts which render practicable the method of transmission of electrical energy hereinafter described.

Among these, and bearing directly upon the invention, are the following; First, that with electrical pressures of the magnitude and character which I have made it possible to produce, the ordinary atmosphere becomes, in a measure, capable of serving as a true conductor for the transmission of the current. Second, that the conductivity of the air increases so materially with the increase of electrical pressure and degree of rarefaction, that it becomes possible to transmit through even moderately rarefied strata of the atmosphere, electrical energy up to practically any amount and to any distance.

The system of transmission comprised in my present invention and which, as above stated, was rendered possible only by the production of apparatus of a character radically new and different from any before known, and which is based upon discoveries made in the investigation of the results produced thereby, consists then in producing at a given point a very high electrical pressure, conducting the current caused thereby to earth and to a terminal at an elevation at which the atmosphere serves as a conductor therefor, and collecting the current by a second elevated terminal at a distance from the first.

In order to attain this result it is necessary to employ an apparatus capable of generating electrical pressures vastly in excess of any heretofore used, and to lead the current to earth and to a terminal maintained at an elevation where the rarefied atmosphere is capable of conducting freely the particular current produced; then, at a distant point, where the energy is to be utilized, to maintain a terminal at or about the same elevation to receive the current and to convey it to earth through suitable means for transforming and utilizing it.

The apparatus which I have invented, and by means of which this method of transmission may be effected, is represented in the accompanying drawing, which is a diagrammatic illustration of the system that is to say, each transformer is shown as comprised of a spiral conductor in fine lines surrounded by a conductor in heavy lines with a very few convolutions.

The transformers, as actually constructed are, in reality, nothing more than this. For example, starting on a spool or roll of hard rubber which may contain a central core of iron wires or strands, an insulated wire is wound until a coil is built up of the desired length. This coil is built up precisely as any other, the wire being wound around the core or spool until its convolutions fill up the space and form one complete layer. The winding is continued in the same way until another layer is formed and so on.

When the desired length of secondary or high tension coil is thus obtained, the primary or low tension coil is wound outside of it, but this latter coil is composed of only a very few turns of wire or conductor, which is of much larger diameter or cross-section than the secondary wire.

The transformer thus consists simply of two concentric coils, the inner coil having very many turns of fine wire, the outer coil a very few turns of coarse wire.

From this plan of construction it follows that one of the high tension terminals is at the centre of secondary coil, and in the use of the coil the other terminal whether it be connected to ground or not is electrically connected to the primary in order that there may be no material difference of potential between the latter and the adjacent convolutions of the secondary.

Assuming that it appears from the above that in the general plan of construction of the coils, only common and well known methods have been pursued, it remains then, to consider the length of the secondary coil. This should be approximately one quarter of the wave length of the electrical disturbance in the circuit, and the reason for it is that the highest possible electrical pressures may be secured at the centre terminals of the secondary coils.

A is a coil, generally of many turns and of very large diameter, wound in spiral form either about a magnetic core or not, as may be desired. C is a second coil formed by a conductor of much larger size and smaller length wound around in proximity to the coil A.

In the transmitting apparatus the coil A constitutes the high tension secondary, and the coil C the primary of much lower tension of a transformer. In the circuit of the primary C is included a suitable source of current G.

One terminal of the secondary A is at the center of the spiral coil, and from this terminal the current is led by a conductor B to a terminal D preferably of large surface formed of or maintained by such means as a balloon at an elevation suitable for the purposes of transmission as before described. The other terminal of the secondary A is connected to earth and, preferably, to the primary also, in order that the latter may be approximately of the same potential as the adjacent portions of the secondary, thus insuring safety.

At the receiving station a transformer of similar construction is employed, but in this case the long coil A[1] constitutes the primary and the short coil C[1] the secondary of the transformer. In the circuit of the latter are arranged lamps L, motors M, or other devices for utilizing the current. The elevated terminal D[1] connects with the center of the coil A[1], and the other terminal of said coil is connected to earth and preferably also to the coil C[1] for the reasons above stated.

The length of the high tension coil of each apparatus should be approximately one-quarter of the wave length of the electrical disturbance in the circuit, this estimate being based on the velocity of propagation of the electrical disturbance through the coil itself and the circuit with which it is designed to be used. To illustrate, in accordance with accepted views, if the rate at which a current traverses the circuit, including the two high tension coils, be 185,000 miles per second, then a frequency of 925 per second would maintain 925 stationary waves in a circuit 185,000 miles long, and each wave would be 200 miles in length. For such a *frequency I should use in each high tension coil a conductor 50 miles in length,* or in general, with due allowance for the capacity of the leading wires and terminals, such length of conductor as would secure the highest electrical pressures at the terminals under the working conditions.

It will be observed that in coils of the character described, the potential gradually increases with the number of turns and the difference of potential between adjacent turns is comparatively small, and a very high potential, impracticable with ordinary coils, may be successfully obtained.

As the main object of the invention is to produce a current of extremely high potential, this object will be facilitated by using a primary current of very considerable frequency, but the frequency of the current is, in large measure, arbitrary, for if the potential be sufficiently high and the terminals of the coils be maintained at a proper elevation there the atmosphere is comparatively rarefied, the intermediate stratum of air will serve as a conductor for the current produced, and the latter will be transmitted through the air with, it may be, even less resistance than through an ordinary copper wire.

The apparatus described, it may be observed, is useful as a means for producing currents of very high potential for other purposes than that of the present system, as, for instance, the coils may be used singly for producing extremely high electrical potentials for any purpose, or used generally in the same manner as other electrical transformers, for the conversion and transmission of electrical energy.

It will be understood that either or both of the coils or transformers and terminals may be movable, as, for instance, when carried by vessels floating in the air, or by ships at sea. In the former case the connection of one terminal with the ground might not be permanent, but might be intermittently or inductively established without departing from the spirit of the invention.

As to the elevation of the terminals D, D[1], it is obvious that this is a matter which will be determined not only by the condition of the atmosphere but also by the character of the surrounding country.

Thus, if there be high mountains in the vicinity, the terminals should be at a greater height, and, generally, they should always be at an altitude much greater than that of the highest objects near them in order to reduce the loss by leakage. Since, by the means described, practically any potential that is desired may be produced, the currents through the air strata may be very small, thus reducing the loss in the air.

It will be observed that the phenomenon here involved in the transmission of electrical energy is one of true conduction, and is not to be confounded with the phenomena of induction or of electrical radiation which have heretofore been observed and experimented with, and which, from their very nature and mode of propagation, would render practically impossible the transmission of any considerable amount of energy to such distances as would be of practical importance.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, as communicated to me by my *foreign correspondent*, I declare that what I claim is:—

1. The method of transmitting electrical energy herein described, which consists in producing at a given point a very high electrical pressure, conducting the current caused thereby to earth and to a terminal at an elevation at which the atmosphere serves as a conductor therefor, and collecting the current by a second elevated terminal at a distance from the first, as set forth.

2. A system for the transmission of electrical energy comprising in combination a source of current of very high pressure, connected respectively with earth and with a terminal at an elevation where the atmosphere forms a conducting path for the current produced, a second elevated terminal at a distance from the first for receiving the current transmitted therefrom and means for utilizing the said current, as set forth.

3. The transformer herein described for developing or converting currents of high potential, comprising a low tension and a high tension coil, one terminal of the high tension coil being electrically connected with the low tension coil and with earth when the transformer is in use, as set forth.

4. The transformer herein described for developing or converting currents of high potential, comprising a low tension coil and a high tension coil wound in the form of a flat spiral, the end of the high tension coil adjacent to the low tension coil being electrically connected therewith and with earth when the transformer is in use.

5. The transformer herein described for developing or converting currents of high potential in which the low tension coil and the high tension coil are wound in the form of a spiral, the coil of high tension being inside of, and surrounded by, the convolutions of the other and having its adjacent terminal electrically connected therewith and with earth when the transformer is in use, as set forth.

Dated this 21st day of October 1897.

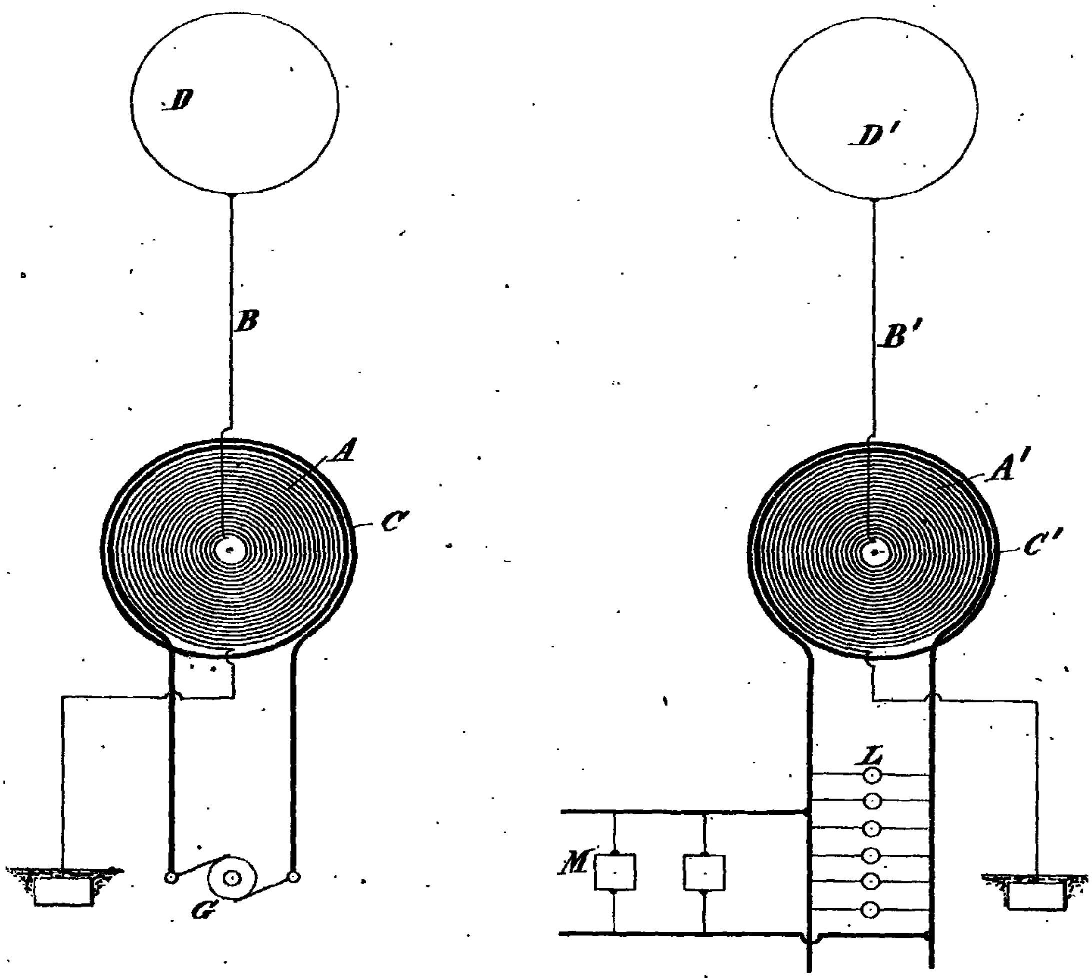
HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, W.C., Agents for the Applicant.

Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd.—1898

A.D. 1897. Oct. 21. N°. 24,421.

LAKE'S Complete Specification.

(1 SHEET)



[This Drawing is a reproduction of the Original on a reduced scale.]

N° 26,371 A.D. 1898

(*Under International Convention.*)

Date claimed for Patent under Sect. 103 of Act, being date of first Foreign Application (in United States), } *1st July, 1898*

Date of Application (in United Kingdom), 13th Dec., 1898

Complete Specification Left, 13th Dec., 1898—Accepted, 9th Dec., 1899

COMPLETE SPECIFICATION.

Improvements in the Method of and Apparatus for Controlling the Mechanism of Floating Vessels or Moving Vehicles.

I, Nikola Tesla, of 46, East Houston Street, New York, United States of America, Electrician, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The problem for which the invention forming the subject of the present application, affords a complete and practicable solution, is that of controlling from a given point the operation of the propelling engines, the steering apparatus and other mechanism carried by a moving object, such as a boat, or any floating vessel, or carriage, such as an automobile, whereby the movements and course of such body or vessel may be directed and controlled from a distance, and any device carried by the same, brought into action at any desired time.

So far as I am aware, the only attempts to solve this problem which have heretofore met with any measure of success, have been made in connection with a certain class of vessels, the machinery of which was governed by electric currents conveyed to the controlling apparatus through a flexible conductor. But this system is subject to such obvious limitations as are imposed by the length, weight and strength of the conductor which can be practically used, by the difficulty of maintaining with safety a high speed of the vessel or changing the direction of movement of the same with the desired rapidity, by the necessity for effecting the control from a point which is practically fixed, and by many well-understood drawbacks inseparably connected with such a system.

The plan which I have perfected involves none of these objections for I am enabled by the use of my invention to employ any means of propulsion, to impart to the moving body or vessel the highest possible speed, to control the operation of its machinery and to direct its movements from whether a fixed point or from a body moving and changing its direction however rapidly, and to maintain this control over great distances, without any artificial connections between the vessel and the apparatus governing its movements, and without such restrictions as these must necessarily impose.

In a broad sense, then, my invention differs from all of those systems which provide for the control of the mechanism carried by a moving object and governing its motion, in that I require no intermediate wires, cables or other form of electrical or mechanical connection with the object save the natural media in space. I accomplish, nevertheless, similar results and in a much more practicable manner by producing waves, impulses or radiations which are received through the earth, water or atmosphere by suitable apparatus on the moving body and cause the desired actions, so long as the body remains within the active region or effective range of such currents, waves, impulses or radiations.

The many and different requirements of the object here contemplated, involving peculiar means for transmitting to a considerable distance an influence capable of causing, in a positive and reliable manner, these actions, necessitated the designing of devices and apparatus of a novel kind in order to utilize to the best advantage various facts or results which, either through my own investigations or those of others, have been rendered practically available.

As to that part of my invention which involves the production of suitable waves or variations and the conveying of the same to a remote receiving apparatus capable of being operated or controlled by their influence, it may be carried out in various ways which are at the present time more or less understood. For example, I may pass through a conducting path, preferably enclosing a large area, a rapidly varying current and by electro-magnetic induction of the same, affect a circuit carried by the moving body. In this case the action at a given distance will be the stronger the larger the area enclosed by the conductor and the greater the rate of change of the current. If the latter were generated in the ordinary ways, the rate of change, and consequently the distance at which the action would be practically available for the present purpose, would be very small; but by adopting such means as I have devised, that is—either by passing through the conducting path currents of a specially designed high frequency alternator or better still, those of a strongly charged condenser, a very high rate of change may be obtained, and the effective range of the influence thus extended over a vast area, and by carefully adjusting the circuit on the moving body so as to be in exact electro-magnetic synchronism with the primary disturbances, this influence may be utilized at great distances.

Another way to carry out my invention is to direct the currents or discharges of a high frequency machine or condenser through a circuit, one terminal of which is connected directly or inductively with the ground and the other to a body, preferably of large surface and at an elevation. In this case of the circuit on the moving body be similarly arranged or connected, differences of potential on the terminals of the circuit either by conduction or electrostatic induction are produced, and the same object is attained. Again, to secure the best action, the receiving circuit should be adjusted so as to be in electro-magnetic synchronism with the primary source as before, but in this instance it will be understood by those skilled in the art that, if the number of vibrations per unit of time be the same, the circuit should now have a length of conductor only one half of that used in the former case.

Still another way is to pass the currents simply through the ground by connecting both the terminals of the source of high frequency currents to earth at different and remote points and to utilize the currents spreading through the ground for effecting a receiving circuit properly placed and adjusted. Again, in this instance, if only one of the terminals of the receiving circuit be connected to the ground—the other terminal being insulated—the adjustment as to synchronism with the source will require that under otherwise equal conditions the length of wire be half of that which would be used if both the terminals be connected or, generally, if the circuit be in the form of a closed loop or coil. Obviously also, in the latter case, the relative position of the receiving and transmitting circuits is of importance, whereas, if the circuit be of the former kind, that is, open, the relative position of the circuits is, as a rule, of little or no consequence.

Finally, I may avail myself, in carrying out my invention, of electrical oscillations which do not follow any particular conducting path, but propagate in straight lines through space, of rays, waves, pulses or disturbances of any kind, capable of bringing the mechanism of the moving body into action from a distance and at the will of the operator by their effect upon suitable controlling devices.

In the following detailed description I shall confine myself to an explanation of that method and apparatus only which I have found to be the most practical and effectual, but obviously, my invention in its broad features is not limited to the special mode and appliances which I have devised and shall here describe.

In any event, that is to say—whichever of the above or similar plans I may adopt—and, particularly, when the influence exerted from a distance upon the receiving circuit be too small to directly and reliably affect and actuate the controlling apparatus, I employ auxiliary sensitive relays or, generally speaking, means capable of being brought into action by the feeblest influences, in order to effect the control of the movements of the distant body with the least possible expenditure of energy and at the greatest practicable distance, thus extending the range and usefulness of my invention.

A great variety of electrical and other devices, more or less suitable for the purpose of detecting and utilizing feeble actions, are now well known to scientific men and artisans, and need not be all enumerated here. Confining myself merely to the electrical as the most practicable of such means, and referring only to those which, while not the most sensitive, are, perhaps, more readily available, from the more general knowledge which exists regarding them, I may state that a contrivance may be used which has long been known and used as a lightning arrester, in connection with telephone switchboards for operating annunciators and like devices, comprises a battery, the poles of which are connected to two conducting terminals separated by a minute thickness of dielectric. The electro-motive force of the battery should be such as to strain the thin dielectric layer very nearly to the point of breaking down, in order to increase the sensitiveness. When an electrical disturbance reaches a circuit so arranged and adjusted, additional strain is put upon the insulating film which gives way and allows the passage of a current, which can be utilized to operate any form of circuit controlling apparatus.

Again, another contrivance capable of being utilized in detecting feeble electrical effects, consists of two conducting plates or terminals which have preferably wires of some length attached to them and are bridged by a mass of minute particles of metal or other conducting material. Normally these particles, lying loose, do not connect the metal plates, but under the influence of an electrical disturbance produced at a distance, evidently owing to electrostatic attraction, they are pressed firmly against each other, thus establishing a good electrical connection between the two terminals. This change of state may be made use of in number of ways for the above purpose.

Still another modified device which may be said to embody the features of both the former, is obtained by connecting the two conducting plates or terminals, above referred to, permanently with the poles of a battery which should be of very constant electro-motive force. In this arrangement a distant electrical disturbance produces a two-fold effect on the conducting particles and insulating films between them. The former are brought nearer to each other in consequence of the sudden increase of electrostatic attraction, and the latter, owing to this, as well as by being reduced in thickness or in number, are subjected to a much greater strain which they are unable to withstand.

It will be obviously noted from the preceding that, which ever of these or similar contrivances be used, the sensitiveness and, what is often still more important, the reliability of operation is very materially increased by a close adjustment of the periods of vibration of the transmitting and receiving circuits, and, although such adjustment is in many cases unnecessary for the successful carrying out of my invention, I nevertheless make it a rule to bestow upon this feature the greatest possible care, not only because of the above mentioned advantages which are secured by the observance of the most favorable conditions in this respect, but also, and chiefly, with the object of preventing the receiving circuit from being affected by waves or disturbances emanating from sources not under the control of the operator. The narrower the range of vibrations which are still capable of perceptibly affecting the receiving circuit, the safer will the latter be against extraneous disturbances. To secure the best result it is necessary, as is well known to experts, to construct the receiving circuit, or that part of the same in which the vibration chiefly occurs, so that it will have the highest possible self-induction and at the same time the least possible resistance. In this manner I have demonstrated the practicability of providing a great number of such receiving circuits—fifty or a hundred or more—each of which may be called up or brought into action whenever desired, without the others being interfered with. This result makes it possible for one operator to direct, simultaneously, the movements of a number of bodies, as well as to control the action of a number of devices located on the same body, each of which may have a distinct duty to fulfil. In the following description, however, I shall show a still further development in this direction, namely, how, by making use of merely one receiving circuit, a great variety of devices may be actuated and any number of different functions performed at the will and command of the distant operator.

It should be stated in advance, in regard to the sensitive devices above mentioned, which may be broadly considered as belonging to one class—inasmuch as the operation of all of them involves the breaking down of a minute thickness of highly strained dielectric—that it is necessary to make some provision for automatically restoring to the dielectric its original, unimpaired insulating qualities, in order to enable the device to be used in successive operations.

This is usually accomplished by a gentle tapping or vibration of the electrodes or particles, or continuous rotation of the same, but in long experience with many forms of these devices I have found that such procedures, while suitable in simple and comparatively unimportant operations, as ordinary signalling, when it is merely required that the succeeding effects produced in the receiving circuit should differ in regard to their relative duration only,—in which case it is of little or no consequence if some of the individual effects be altered, or incomplete, or even entirely missed—do not yield satisfactory results in many instances, when it may be very important that the effects produced should all be exactly such as desired and that none should fail. To illustrate, let it be supposed that an official, directing the movements of a vessel in the manner described, should find it necessary to bring into action a special device on the latter, or to perform a particular operation, perhaps of vital moment, at an instant's notice and possibly when, by design or accident, the vessel itself or any mark indicating its presence is hidden from his view. In this instance a failure or defective action of any part of the apparatus might have disastrous consequences and such cases, in which the sure and timely working of the machinery is of paramount importance, may often present themselves in practice, and this consideration has impressed me with the necessity of doing away with the defects in the present devices and procedures and of producing an apparatus which, while being sensitive, will also be most reliable and positive in its action. In the arrangement hereinafter described these defects are overcome is a most satisfactory manner, enabling thousands of successive operations, in all respects alike, being performed by the controlling apparatus without a single irregularity or miss being recorded. For a better understanding of these and other details of the invention as I now carry them out, I would refer to the accompanying drawings, in which:

Figure 1 is a plan view of a vessel and mechanism within the same.

Figure 2 is a longitudinal section of the same showing the interior mechanism in side elevation.

Figure 3 is a plan view, partially diagrammatical, of the vessel, apparatus and circuit connections of the same.

Figure 4 is a plan view on an enlarged scale of a portion of the controlling mechanism.

Figure 5 is an end view of the same.

Figure 6 shows the same mechanism in side elevation.

Figure 7 is a side view of a detail of the mechanism.

Figure 8 is a central sectional view on a larger scale of a sensitive device forming part of the receiving circuit.

Figure 9 is a diagrammatic illustration of the system in its preferred form.

Figure 10 is a view of the various mechanism employed but on a larger scale and leaving out or indicating conventionally certain parts of well understood character.

Referring to Figure 1 and Figure 2, A designates any type of vessel or vehicle which is capable of being propelled and directed, such as a boat, or a carriage such as an automobile. It may be designed to carry, in a suitable compartment B, objects of any kind, according to the nature of the uses to which it is to be applied. The vessel, in this instance, a boat, is provided with suitable propelling machinery which is shown as comprising a screw propellor C, secured to the shaft of an electro-magnetic motor D, which derives its power from storage batteries E, E, E, E.

In addition to the propelling engine or motor, the boat carries also a smaller steering motor F, the shaft of which is extended beyond its bearings and provided with a worm which meshes with a toothed wheel G. This latter is fixed to a sleeve *b*, freely movable on a vertical rod H, and is rotated in one or the other direction according to the direction of rotation of the motor F.

The sleeve *b* on rod H is in gear through the cog wheels H^1 and H^{11} with a spindle G^1 mounted in vertical bearings at the stem of the boat and carrying the rudder F^1.

The apparatus, by means of which the operation of both the propelling and steering mechanism is controlled, involves, primarily, a receiving circuit which, for reasons before stated, is preferably both adjusted and rendered sensitive to the influence of waves or impulses emanating from a remote source, the adjustment being so that the period of oscillation of the circuit is either the same as that of the source or a harmonic thereof.

The receiving circuit proper, diagrammatically shown in Figures 3 and 10, comprises a terminal E^1, conductor C^1, a sensitive device A^1 and a conductor A^{11} leading to the ground, conveniently through a connection to the metal keel B^1 of the vessel.

The terminal E^1 should present a larger conducting surface and should be supported as high as practicable on a standard D^1, which is shown as broken in Figure 2, but such provisions are not always necessary. It is important to insulate very well the conductor C^1, in whatever manner it be supported.

The circuit or path just referred to forms also a part of a local circuit, which latter includes a relay magnet *a* and a battery a^1, the electro-motive force of which is, as before explained, so determined that although the dielectric layers in the sensitive device A^1 are subjected to a great strain, yet normally they withstand the strain and no appreciable current flows through the local circuit. But when an electrical disturbance reaches the circuit, the dielectric films are broken down, the resistance of the device A^1 is suddenly and greatly diminished and a current traverses the relay magnet *a*.

The particular sensitive device employed is shown in general views and in detail in Figures 4, 6, 7 and 8. It consists of a metal cylinder *c* with insulating heads c^1, through which passes a central metallic rod c^{11}. A small quantity of grains d of conducting material, such as an oxidized metal is placed in the cylinder.

A metallic strip d^1, secured to an inclined post d^{11} bears against the side of the cylinder c, connecting it with the conductor C^1 forming one part of the circuit. The central rod c^{11} is connected to the frame of the instrument and so to the other part of the circuit through the forked metal arm e, the ends of which are fastened with two nuts to the projecting ends of the rod, by which means the cylinder c is supported.

In order to interrupt the flow of battery current which is started through the action of the sensitive device A^1 special means are provided, which are as follows: The armature e^1 of the magnet a, when attracted by the latter, closes a circuit containing a battery b^1 and magnet f. The armature lever f^1 of this magnet is fixed to a rock shaft f^{11}, to which is secured an anchor escapement g which controls the movements of a spindle g^1 driven by a clock train K.

The spindle g^1 has fixed to it a disk g^{11} with four pins h^{11}, so that for each oscillation of the escapement g the spindle g^1 is turned through one quarter of a revolution.

One of the spindles in the clock train, as h, is geared so as to make one half of a revolution for each quarter revolution of the spindle g^1. The end of the former spindle extends through the side of the frame and carries an eccentric cylinder h^1 which passes through a slot in a lever h^{11} pivoted to the side of the frame.

The forked arm e which supports the cylinder c is pivoted to the end of eccentric h^1, and the eccentric and said arm are connected by a spiral spring i.

Two pins i^1, i^1, extend out from the lever h^{11}, and one of these is always in the path of a projection on arm e. They operate to prevent the turning of cylinder c with the spindle h and the eccentric. It will be evident that a half revolution of the spindle h will wind up the spring i and at the same time raise or lower the lever h^{11}, and these parts are so arranged that just before the half revolution of the spindle is completed the pin i^1, in engagement with projection or stop pin p, is withdrawn from its path and the cylinder c, obeying the force of the spring i, is suddenly turned end for end, its motion being checked by the other pin i^1.

The adjustment relatively to armature f^1 or magnet f is furthermore so made, that the pin i^1 is withdrawn at the moment when the armature has nearly reached its extreme position in its approach towards the magnet, that is, when the lever l which carries the armature f^1, almost touches the lower one of the two stops s s, Figure 5, which limits its motion in both directions.

The arrangement just described has been the result of long experimenting with the object of overcoming certain defects in devices of this kind, to which reference has been made before. These defects I have found to be due to many causes as, the unequal size, weight and shape of the grains, the unequal pressure which results from this and from the manner in which the grains are usually agitated, the lack of uniformity in the conductivity of the surface of the particles owing to the varying thickness of the superficial oxidized layer, the varying condition of the gas or atmosphere in which the particles are immersed and to certain deficiences, well known to experts, of the transmitting apparatus as heretofore employed, which are in a large measure reduced by the use of my improved high frequency coils. To do away with the defects in the sensitive device, I prepare the particles so that they will be in all respects as nearly alike as possible. They are manufactured by a special tool insuring their equality in size, weight and shape, and are then uniformly oxidized by placing them for a given time in an acid solution of predetermined strength. This secures equal conductivity of their surfaces and stops their further deterioration, thus preventing a change in the character of the gas in the space in which they are inclosed. I prefer not to rarefy the atmosphere within the sensitive device, as this has the effect of rendering the former less constant in regard to its dielectric properties, but merely secure an air-tight inclosure of the particles and rigorous absence of moisture, which is fatal to satisfactory working.

The normal position of the cylinder *c* is vertical and when turned in the manner described, the grains in it are simply shifted from one end to the other. But inasmuch as they always fall through the same space and are subjected to the same agitation, they are brought, after each operation of the relay, to precisely the same electrical condition, and offer the same resistance to the flow of the battery current until another impulse from afar reaches the receiving circuit.

The relay magnet *a* should be of such character as to respond to a very weak current and yet be positive in its action. To insure the retraction of its armature e^1 after the current has been established through the magnet *f* and interrupted by the inversion of the sensitive device *c*, a light rod *k* is supported in guides on the frame in position to be lifted by an extension k^1 of the armature lever *l* and to raise slightly the armature e^1. As a feeble current may normally flow through the sensitive device and the relay magnet *a*, which would be sufficient to hold, though not draw the armature down, it is well to observe this precaution.

The operation of the relay magnet *a* and the consequent operation of the electro-magnet *f*, as above described, are utilized to control the operation of the propelling engine and the steering apparatus in the following manner;

On the spindle g^1 which carries the escapement disc g^{11}, Figure 4 and Figure 6, is a cylinder *j* of insulating material with a conducting plate or head at each end. From these two heads, respectively, contact plates or segments j^1 j^{11}, extend on diametrically opposite sides of the cylinder. The plate j^{11} is in electrical connection with the frame of the instrument through the head from which it extends, while insulated strips or brushes J J^1 bear upon the free end or head of the cylinder and the periphery of the same respectively. Three terminals are thus provided, one always in connection with plate j^1, the other always in connection with the plate j^{11}, and the third adapted to rest on the strips j^1 and j^{11} in succession or upon the intermediate insulating spaces, according to the position in which the commutator is brought by the clock train and the anchor escapement *g*.

K^1 K^{11}, Figures 1, 3 and 10, are two relay magnets, conveniently placed in the rear of the propelling engine. One terminal of a battery k^{11} is connected to one end of each of the relay coils; the opposite terminal to the brush J^1, and the opposite ends of the relay coils to the brush J, and to the frame of the instrument respectively. As a consequence of this arrangement either the relay K^1 or K^{11} will be energized, as the brush J^1 bears upon the plate j^1 or j^{11} respectively, or both relays will be inactive while the brush J^1 bears upon an insulating space between the plates j^1 and j^{11}.

While one relay, as K^1, is energized, its armature closes a circuit through the motor F, which is rotated in a direction to throw the rudder to port. On the other hand, when relay K^{11} is active, another circuit through the motor F is closed which reverses its direction of rotation and shifts the rudder to starboard. These circuits however, are at the same time utilized for other purposes, and their course is, in part, through apparatus which I shall describe before tracing their course.

The fixed rod H carries an insulating disc or head L, Figure 2, to the under side of which are secured six brushes, 1, 2, 3, 4, 5, and 6, Figure 3. The sleeve *b* which surrounds the rod and is turned by the steering motor F carries a disc L^1, upon the upper face of which are two concentric circles of conducting contact plates. Brushes 1, 2, 3 and 4 bear upon the inner circle of contacts, while the brushes 5 and 6 bear upon the outer circle of contacts.

The outer circle of contacts comprises two long plates 7 and 8 on opposite sides of the disc, and a series of shorter plates, 9, 10, 11, 12, 13 and 14 in the front and rear. Flexible conductors l^{1}, l^{11} connect the plates 7 and 8 with the terminals of the propelling motor D, and the poles of the main battery E are connected to the brushes 5 and 6 respectively, so that, while the rudder is straight or turned up to a certain angle to either side, the current is conveyed through the brushes 5 and 6 and segments 7 and 8 to the propelling motor D.

The steering motor F is also driven by current taken from the main battery E in the following manner. A conductor 15 from one pole of the battery leads to one of the commutator brushes, and from the other brush runs a conductor 16, to one of the contacts of each relay $K^{1} K^{11}$. When one of these relays, as K^{11}, is active, it continues this circuit through a wire 19, through one field coil or set of coils on the motor F, and thence to the brush 1. In a similar manner, when the other relay K^{1} is active, the circuit is continued from wire 18 through a wire 20, the second or reversing set of fluid coils and to brush 2.

Both brushes 1 and 2, at all times when the rudder is not turned more than about forty-five degrees to one side, are in contact with a long conducting plate 21, and one brush in any position of the rudder is always in contact with said plate, and the latter is connected by a flexible conductor 22 with the opposite pole of the main battery. Hence the motor F may always be caused to rotate in one direction, whatever may be the position of the rudder, and may be caused to rotate in either direction whenever the position of the rudder is less than a predetermined angle, conveniently forty-five degrees from the centre position.

In order, however, to prevent the rudder from being turned too far in either direction, the isolated plate 23 is used. Any movement of the rudder beyond a predetermined limit brings this plate under one or the other of the brushes 1, 2, and breaks the circuit of motor F, so that the rudder can be driven no further in that direction, but, as will be understood, the apparatus is in condition to turn the rudder over to the other side.

In like manner the circuit of the propelling motor D is controlled through brushes 5 and 6 and the segments on the outer circle of contacts of head L. If the short segments on either side of the circle are insulated the motor D will be stopped whenever one of the brushes 5 or 6 passes onto one of them from the larger segments 7, 8.

It is important to add that on all contact points where a break occurs, provision should be made to overcome the sparking and prevent the oscillation of electrical charges in the circuits, as such sparks and oscillations may affect the sensitive device. It is this consideration chiefly, which makes it advisable to use the two relays $K^{1} K^{11}$ which otherwise might be dispensed with. They should be also placed as far as practicable from the sensitive device in order to guard the latter against any action of strong varying currents.

In addition to the mechanism described the vessel may carry any other devices or apparatus as might be required for accomplishing any special object of more or less importance. By way of illustration, a small motor *m* is shown (Figures 1 and 3), which conveniently serves for a number of purposes. This motor is shown connected in series with the armature of the steering motor F, so that whenever either one of the circuits of the latter is closed through relays $K^{1} K^{11}$, the motor *m* is likewise rotated, but in all cases in the same direction. Its rotation is opposed by a spring m^{1} so that in normal operation, owing to the fact that the circuits of motor F are closed but a short time, the lever m^{11} which is fastened to one of the wheels of clockwork M, with which the armature of the motor is geared, will move but a short distance, and upon cessation of the current return to a stop P. But if the circuits of the motor F are closed and opened rapidly in succession, which operation leaves the rudder unaffected, then the lever m^{11} is moved to a greater angle, coming in contact with a metal plate *n*, and finally, if desired, with a post n^{1}.

Upon the lever m^{11} coming in contact with plate n, the current of the main battery passes either through one or other or both of the lights supported on standards $q\,q$, according to the position of brushes 3 and 4 relatively to the insulating segment 23. But since the head L^1 carrying the segments is geared to the rudder, the position of the latter is in a general way determined by observing the lights. Both of the lights may be colored, and by flashing them up whenever desired, the operator may guide at night the vessel in its course. For such purposes also the standards $r\,r$ are provided, which should be painted in lively colors so as to be visible by day at great distances.

By opening and closing the circuits of motor F a greater number of times, preferably determined beforehand, the lever m^{11} is brought in contact with post n^1, thus closing the circuit of the main battery through a device o Figure 10 and bringing the latter into action at the moment desired. By similar contrivances, or such as will readily suggest themselves to mechanicians, any number of different devices may be operated.

Referring now to Figure 9, which illustrates diagrammatically the system as practised when directing the movements of a boat;

In this figure S designates any source of electrical disturbance or oscillations, the generation of which is controlled by a suitable switch contained in box T. The handle of the switch is movable in one direction only and stops on four points $t\,t^1\,u\,u^1$, so that, as the handle passes from stop to stop, oscillations are produced by the source during a very short time interval. There are thus produced four disturbances during one revolution, and the receiving circuit is affected four times, but it will be understood from the foregoing description of the controlling devices on the vessel, that the rudder will be moved twice, once to right and once to left. Now I preferably place the handle of the switch so that when it is arrested on points $t\,t^1$, that is, to the right or left of the operator, he is reminded that the vessel is being deflected to the right or left from its course, by which means the control is facilitated. The normal positions of the handle are therefore at $u\,u^1$, when the rudder is not acted upon, and it remains on the points $u\,u^1$, only so long as necessary. Since, as before stated, the working of the apparatus is very sure the operator is enabled to perform any such operations as provision is made for, without even seeing the vessel.

The manner of using the apparatus and the operation of the several instrumentalities comprising the same is, in detail as follows: Normally, the plate L^1 is turned so that brush 2 rests upon the insulated segment 23, and brush 6 upon one of the isolated short segments in the rear of the circle. Under these conditions the rudder will be turned to starboard, and the circuit of motor D interrupted between brushes 5 and 6. At the same time, only one of the circuits of motor F,—that controlled by relay K^1—is capable of being closed, since brush 2, which connects with the other, is out of contact with the long segment 21.

Assuming now that it is desired to start the vessel and direct it to a given point. The handle T is turned from its normal position on point u^1 to the point t on the switch box. This sends out an electrical disturbance which passing through the receiving circuit on the vessel, affects the sensitive device A^1 and starts the flow of current through the local circuit, including said device, the relay a and the battery a^1. This, as has been previously explained, turns the cylinder j and causes the brush J^1 to pass from insulation onto the contact j^1.

The battery k^{11}, and the latter closes that circuit of the motor F which, starting from plate 22, which is permanently connected with one pole of the main battery, is completed through the brush 1, the field of motor F, wire 19, the armature of relay K^{11}, wire 16, the motor m, the brushes and commutator of motor F, and wire 15 to the opposite terminal of the battery E. Motor F is thus set in operation to shift the rudder to starboard, but the movement of plate L^1, which follows, brings the brush 6 back onto segment 8 and closes the circuit of the propelling motor, which starts the vessel.

The motor F is permitted to run until the rudder has been turned sufficiently to steer the vessel in the desired direction, when the handle T is turned to the point *u*. This produces another action of the relay *a* and brush J^1 is shifted onto insulation and both relays K^1 and K^{11} are inactive.

The rudder remains in the position to which it has been shifted by the motor F. If it be then desired to shift it to port, or in the opposite direction to that in which it was last moved, the handle T is simply turned to point t^1 and allowed to remain there until the motor F—which is now operated by relay K^1, the circuit of which is closed by strips J^1 coming into contact with plate j^{11}—has done its work.

The movement of handle T to the next point throws out both relays K^1 and K^{11}, and the next movement causes a shifting of the rudder to port, and so on. Suppose, however, that after the rudder has been set at any angle to its middle position, it be desired to shift it still further in the same direction. In such case the handle is moved quickly over two points, so that the circuit which would move the rudder in the opposite direction is closed for too short a time interval to produce an appreciable effect, and is allowed to rest on the third point until the rudder is shifted to the desired position, when the handle is moved to the next point, which again throws out both relays K^1 and K^{11}. It will be understood that if the handle be held for a sufficiently long time upon either point *t* or t^1 the motor F will simply turn the plate L^1 in one direction or the other until the circuits of motors D and F are broken. It is furthermore evident that one relay K or K^{11} will always be operative to start the motor F.

As previously explained, the longest period of operation of which the motor F is capable under ordinary conditions of use does not permit the motor *m* to shift the arm m^{11} into contact with the plate *n*. But if the handle T be turned with a certain rapidity a series of current impulses will be directed through motor *m*, but, as these tend to rotate the motor F in opposite directions they do not sensibly affect the latter, but act to rotate the motor *m* against the force of the coiled spring.

The invention which I have described will prove useful in many ways. Vessels or vehicles of any suitable kind may be used, as life, despatch, or pilot boats or the like, or for carrying letters, packages, provisions, instruments, objects or materials of any description, for establishing communication with inaccessible regions and exploring the conditions existing in the same, for killing or capturing whales or other animals of the sea, and for many other scientific, engineering or commercial purposes.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The improvement in the art of controlling the movements and operation of a vessel or vehicle herein described, which consists in producing waves or disturbances which are conveyed to the vessel by the natural media, actuating thereby suitable apparatus on the vessel and effecting the control of the propelling engine, the steering and other mechanism by the operation of the said apparatus, as set forth.

2. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in establishing a region of waves or disturbances, and actuating by their influence exerted at a distance the devices on such vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

3. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in establishing a region

of electrical waves or disturbances, and actuating by their influence, exerted at a distance, the devices on said vessel or vehicle, which control the propelling, steering and other mechanism thereon, as set forth.

4. The improvement in the art of controlling the movements and operation of a vessel or vehicle, herein described, which consists in providing on the vessel a circuit controlling the propelling, steering and other mechanism, adjusting or rendering such circuit sensitive to waves or disturbances of a definite character, establishing a region of such waves or disturbances, and rendering by their means the controlling circuit active or inactive, as set forth.

5. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, and mechanism thereon for propelling, steering or operating the same, and a controlling apparatus adapted to be actuated by the influence of the said waves or disturbances at a distance from the source, as set forth.

6. The combination with a source of electrical waves or disturbances of a moving vessel or vehicle, mechanism for propelling, steering or operating the same, a circuit and means therein for controlling said mechanism, and means for rendering said circuit active or inactive through the influence of the said waves or disturbances exerted at a distance from the source, as set forth.

7. The combination with a source of electrical waves or disturbances and means for starting and stopping the same, of a vessel or vehicle, propelling and steering mechanism carried thereby, a circuit containing or connected with means for controlling the operation of said mechanism and adjusted or rendered sensitive to the waves or disturbances of the source, as set forth.

8. The combination with a source of electrical waves or disturbances, and means for starting and stopping the operation of the same, of a vessel or vehicle, propelling and steering mechanism carried thereby, local circuits controlling said mechanism, a circuit sensitive to the waves or disturbances of the source and means therein adapted to control the said local circuits, as and for the purpose set forth.

9. The sensitive device herein described comprising in construction a receptacle containing a material such as particles of oxidized metal forming a part of the circuit, and means for turning the same end for end when the material has been rendered active by the passage through it of an electric discharge, as set forth.

10. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming a part of an electric circuit, an electro-magnet in said circuit, and devices controlled thereby for turning the receptacle end for end when said magnet is energized, as set forth.

11. The sensitive device herein described, comprising in combination a receptacle containing a material such as particles of oxidized metal forming part of an electric circuit, a motor for rotating the receptacle, an electro-magnet in circuit with the material, and an escapement controlled by said magnet and adapted to permit a half revolution of the receptacle when the said magnet is energized, as set forth.

12. The combination with a movable body or vehicle, of a propelling motor, a steering motor and electrical contacts carried by a moving portion of the steering mechanism, and adapted in certain positions of the latter to interrupt the circuit of the propelling motor, a local circuit and means connected therewith for controlling the steering motor, and a circuit controlling the local circuit and means for rendering said controlling circuit sensitive to the influence of electric waves or disturbances exerted at a distance from their source, as set forth.

13. The combination with the steering motor, a local circuit for directing current through the same in opposite directions, a controlling circuit rendered

sensitive to the influence of electric waves or disturbances exerted at a distance from their source, a motor in circuit with the steering motor but adapted to run always in the same direction, and a local circuit or circuits controlled by said motor, as set forth.

Dated this 13th day of December 1898.

HASELTINE, LAKE & Co.,
45, Southampton Buildings, London, W.C.,
Agents for the Applicant.

Redhill: Printed for Her Majesty's Stationery Office, by Malcomson & Co., Ltd.—1899.

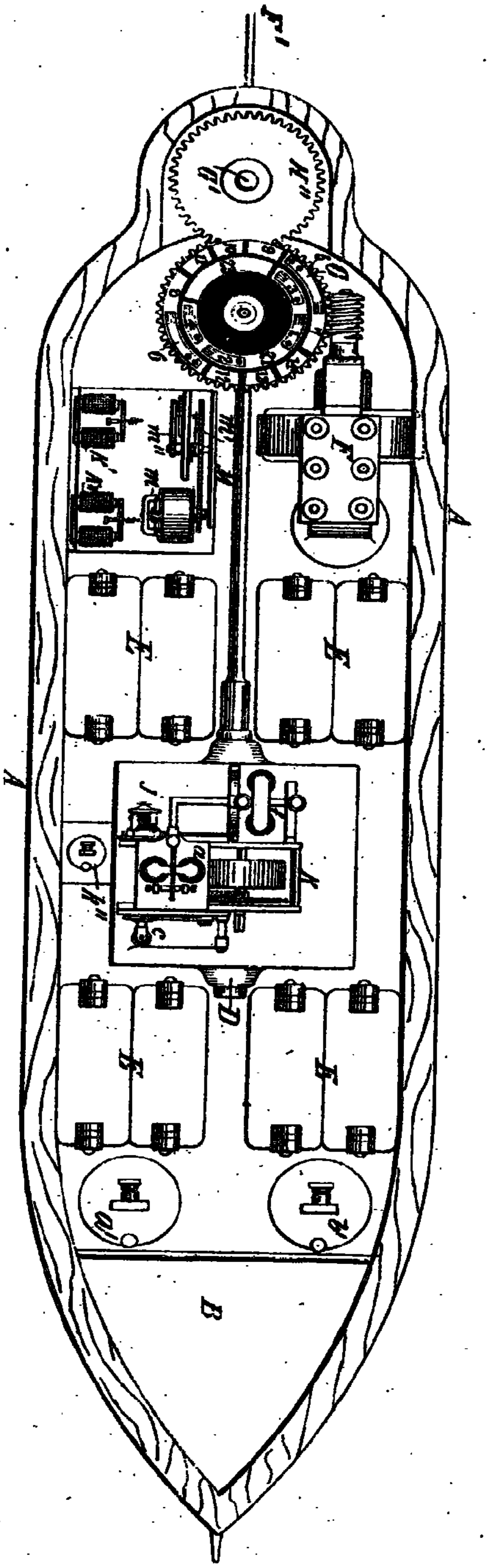


Fig. 1.

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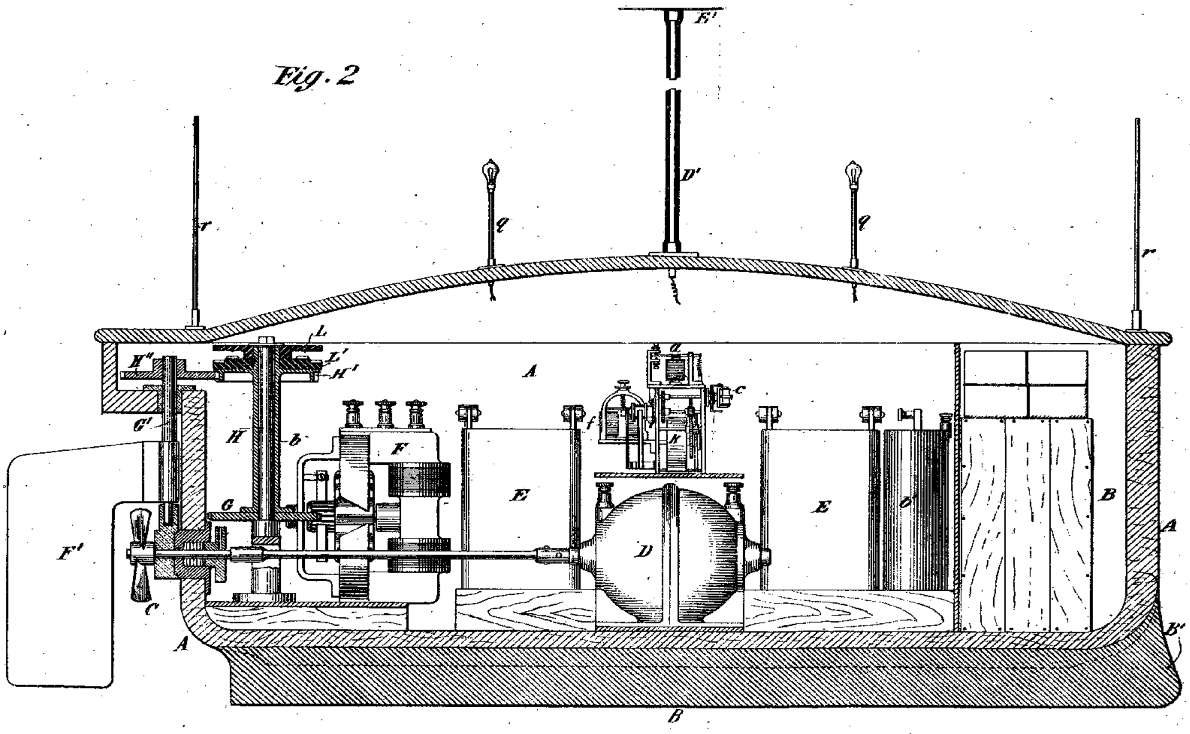
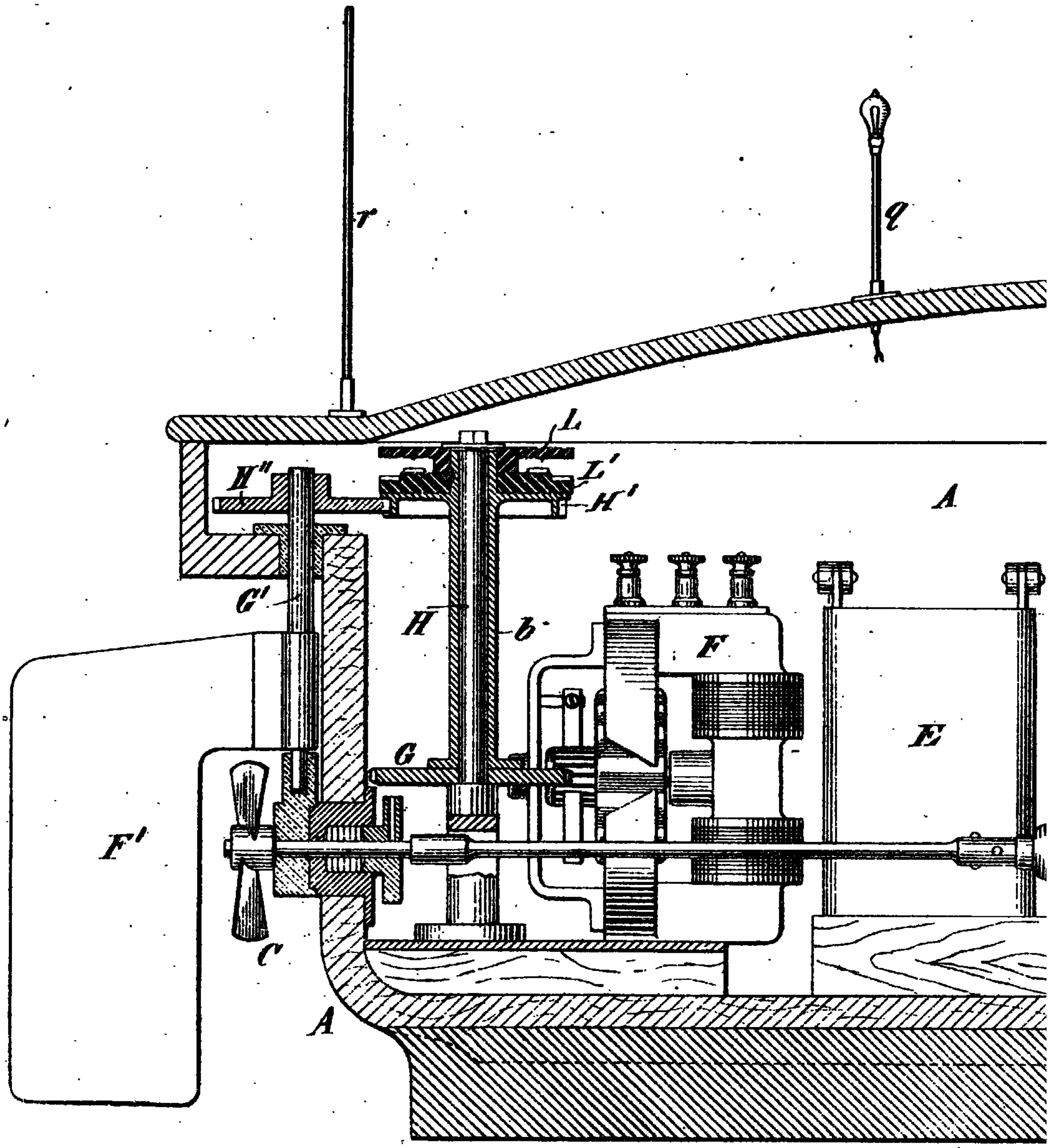
Fig. 2



[This Drawing is a reproduction of the Original on a reduced scale.]

Malby & Sons, Photo-Litho.

Fig. 2



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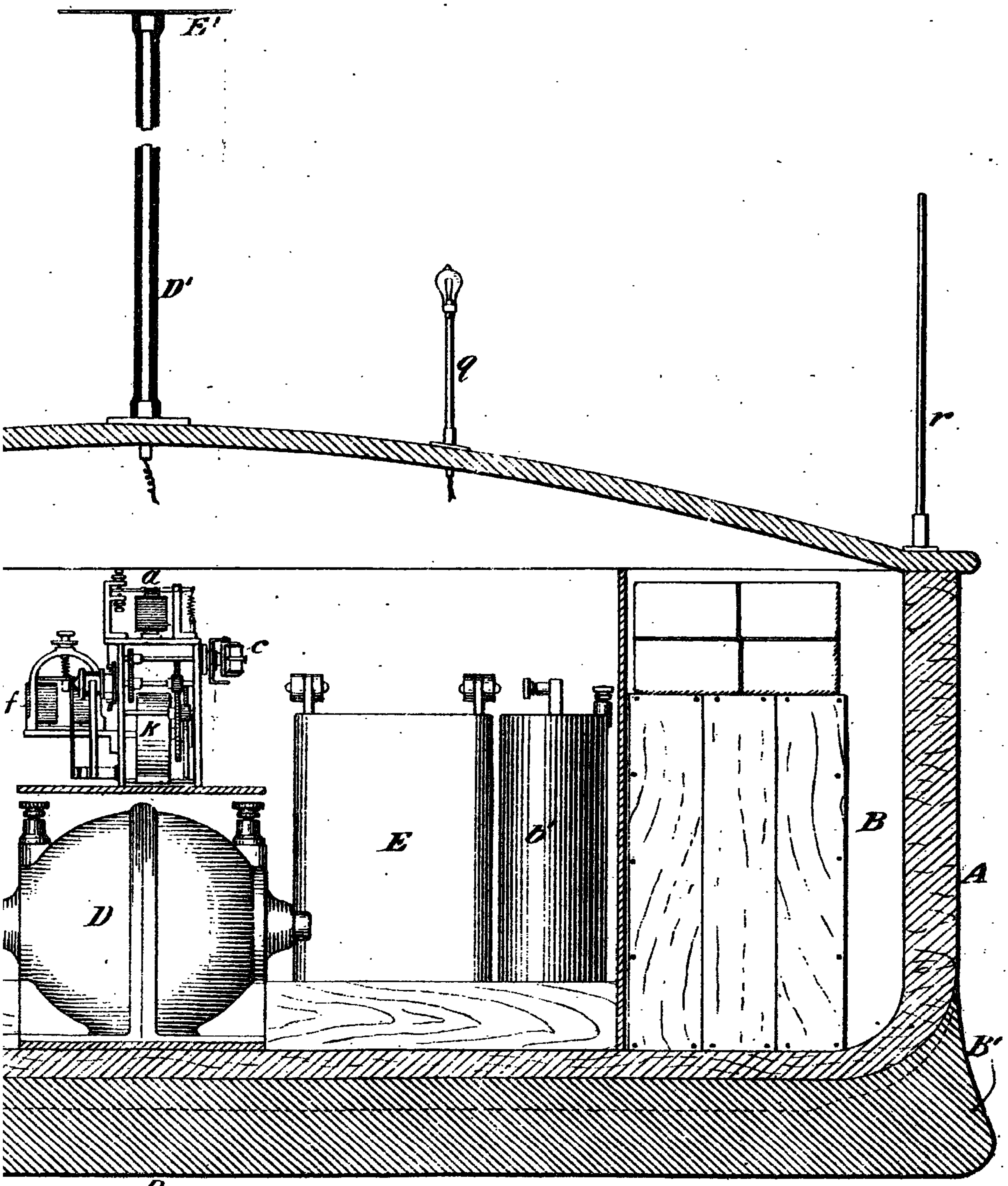

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Fig. 3

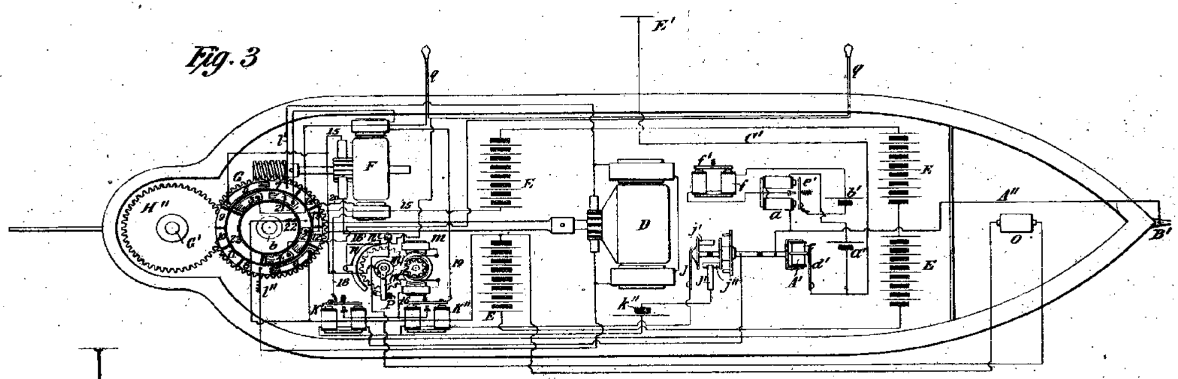

Fig. 9

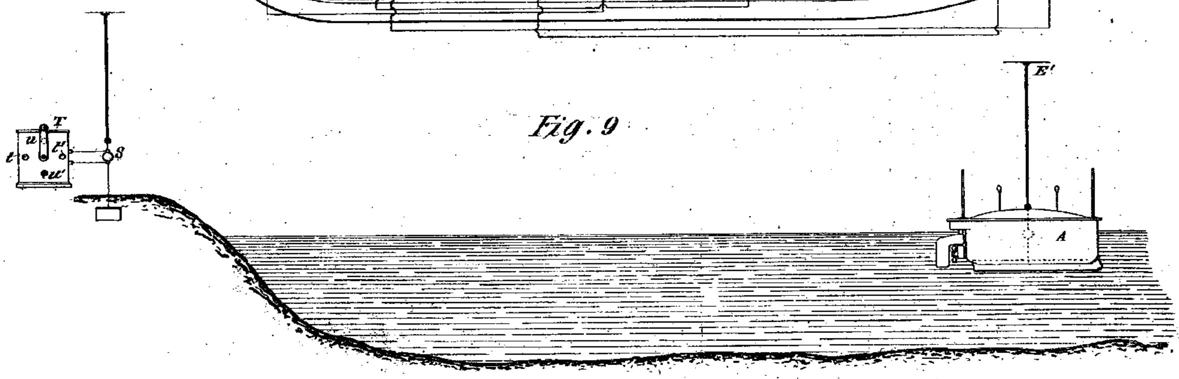

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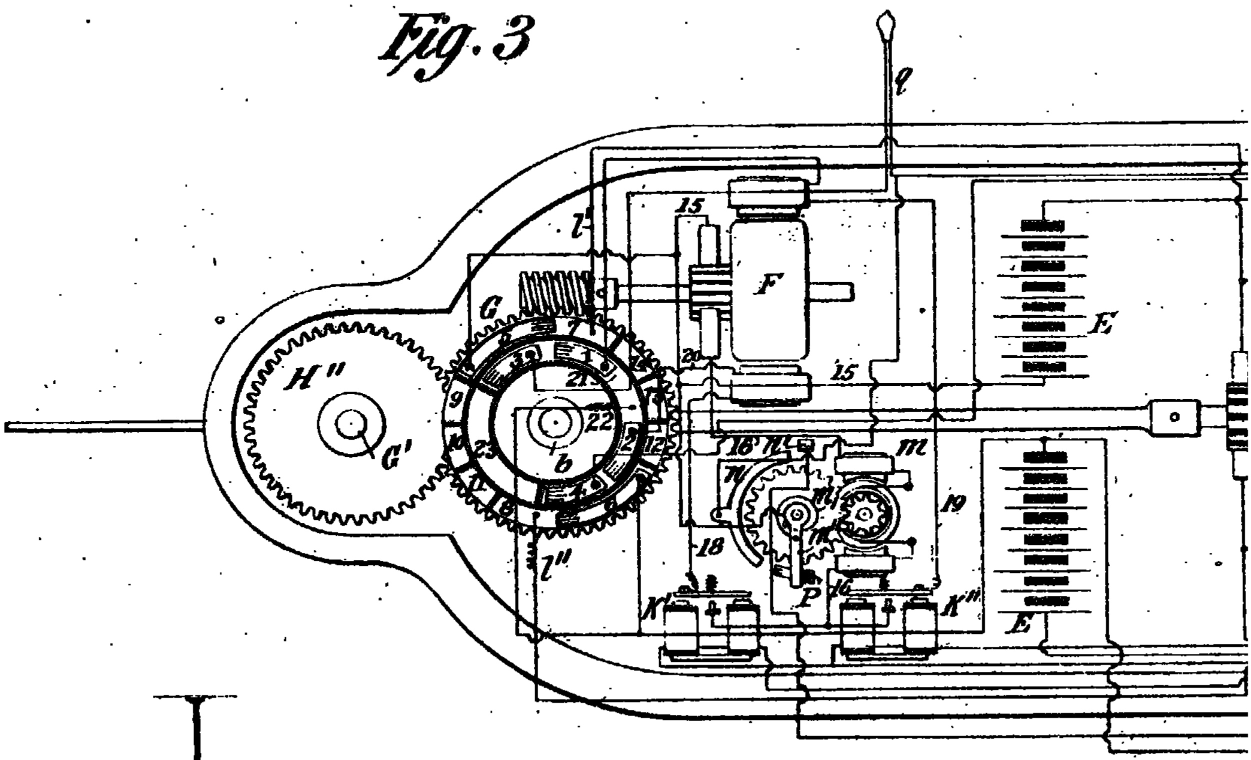
Fig. 3



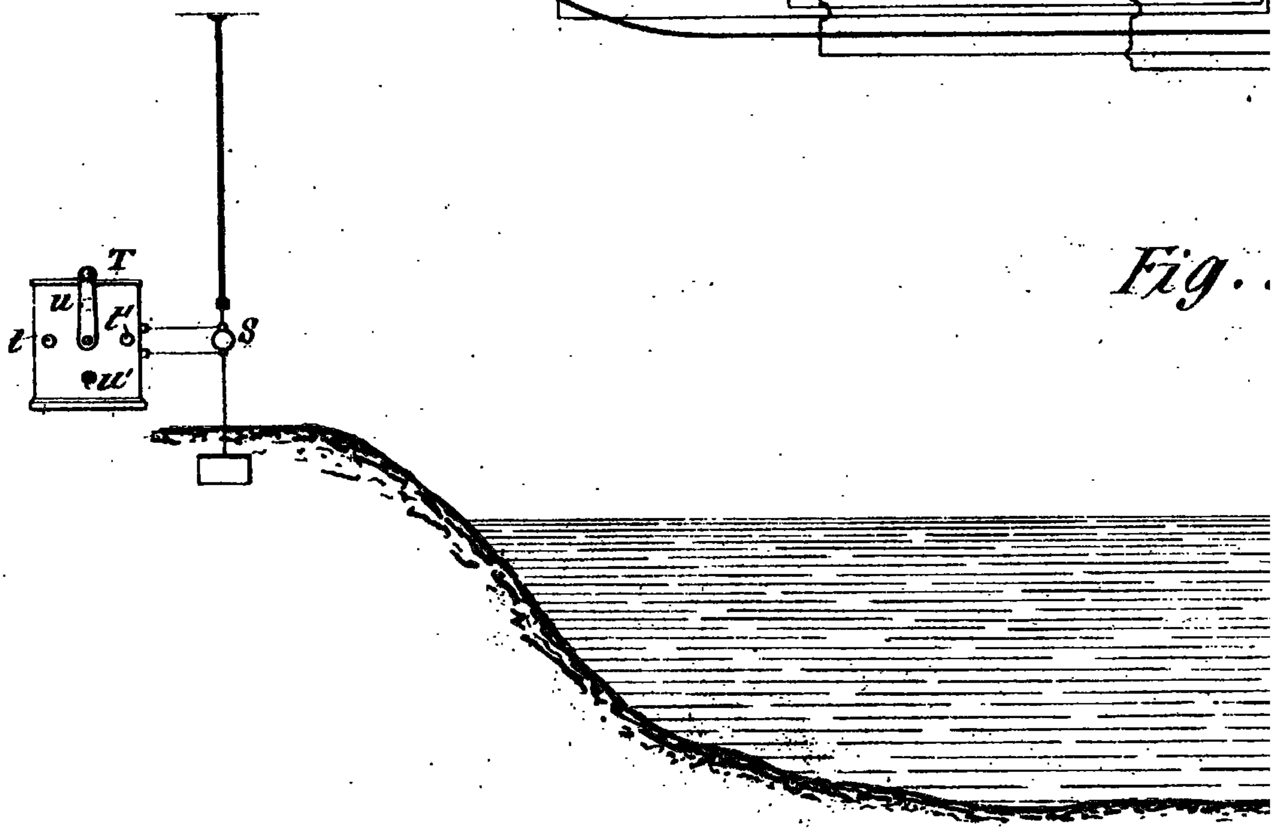
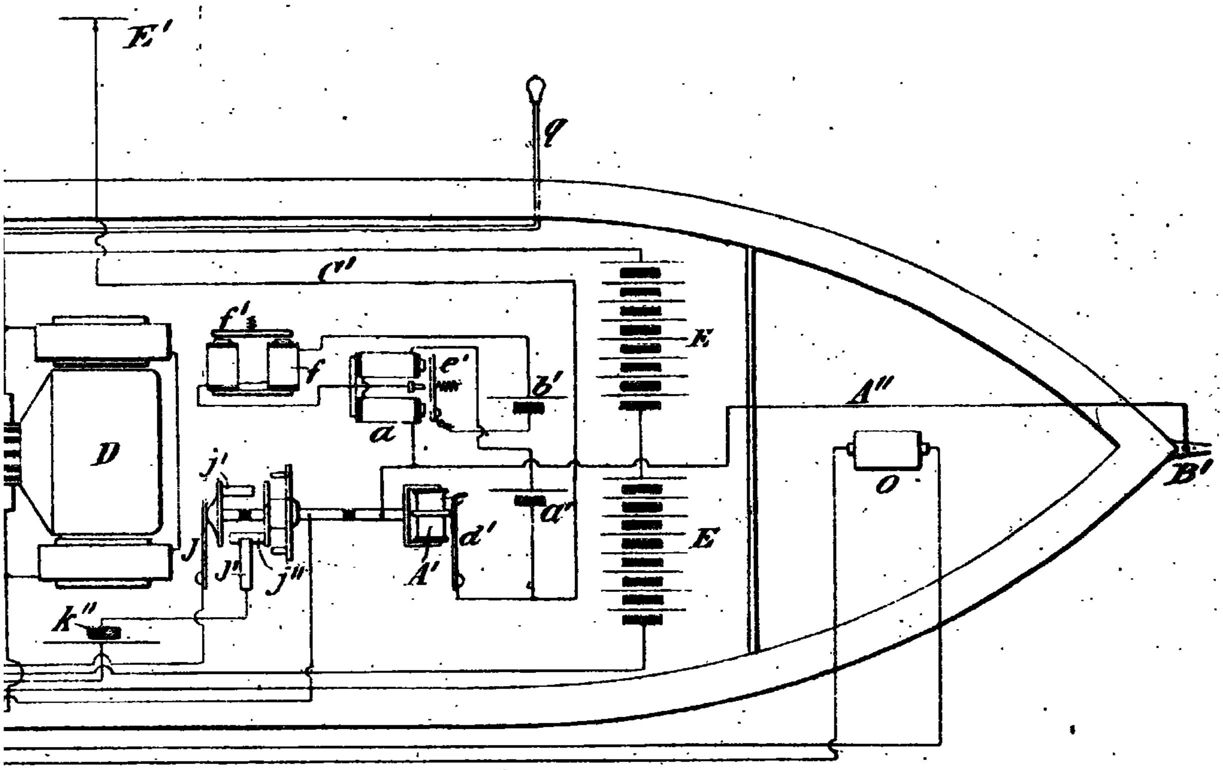


Fig.



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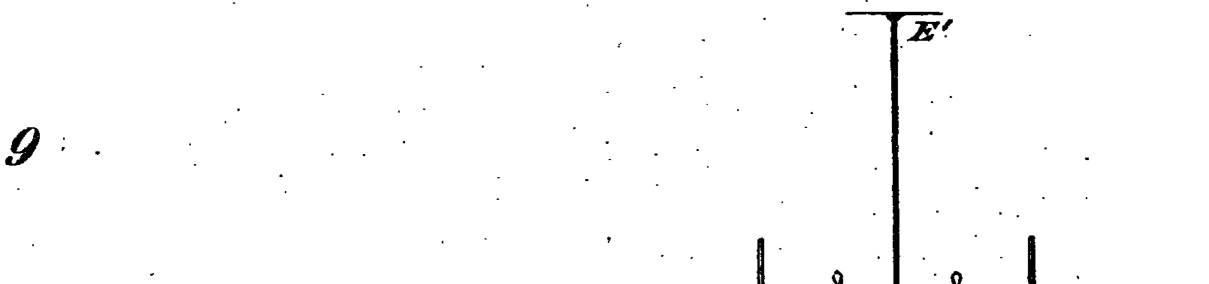

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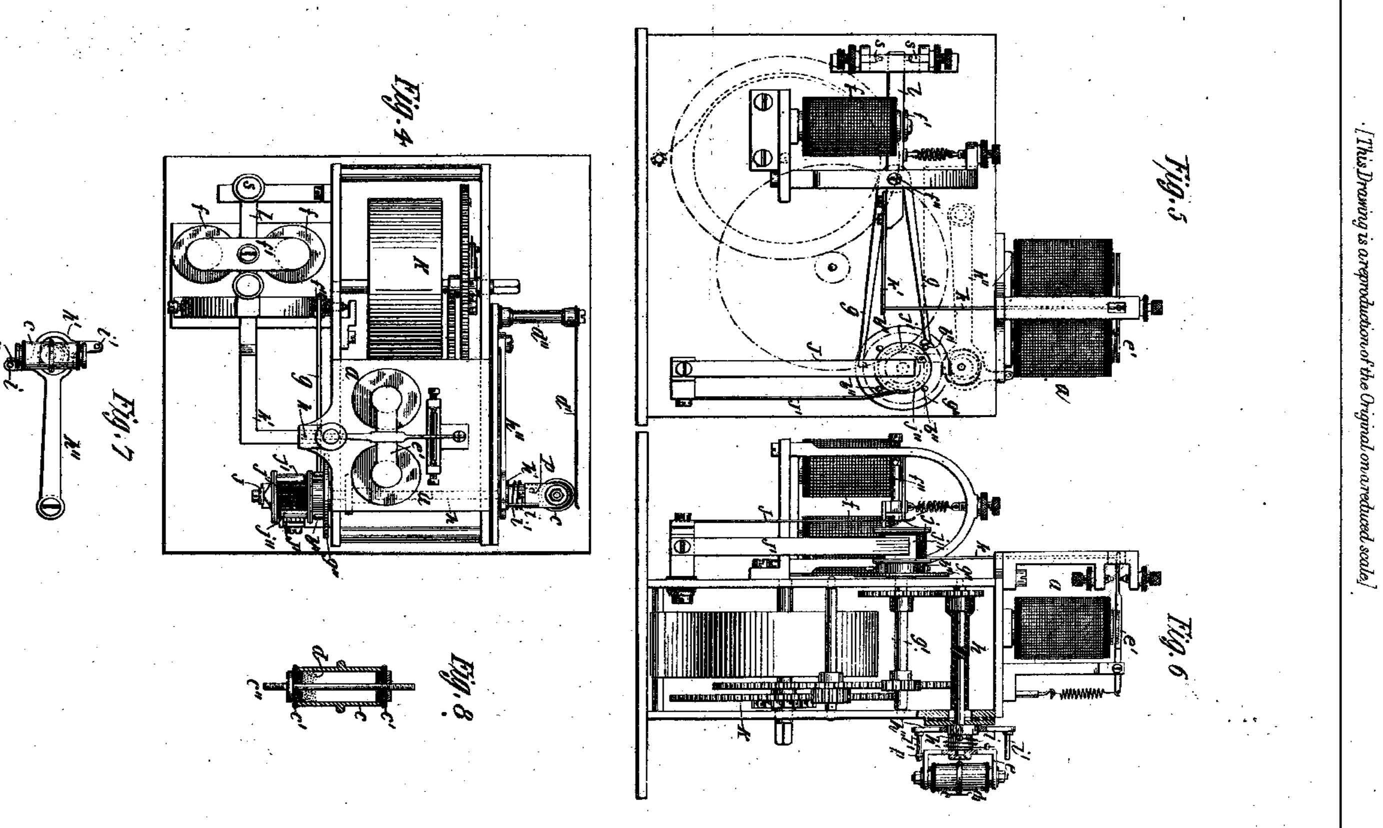
Fig. 4
Fig. 5
Fig. 6
Fig. 7
Fig. 8
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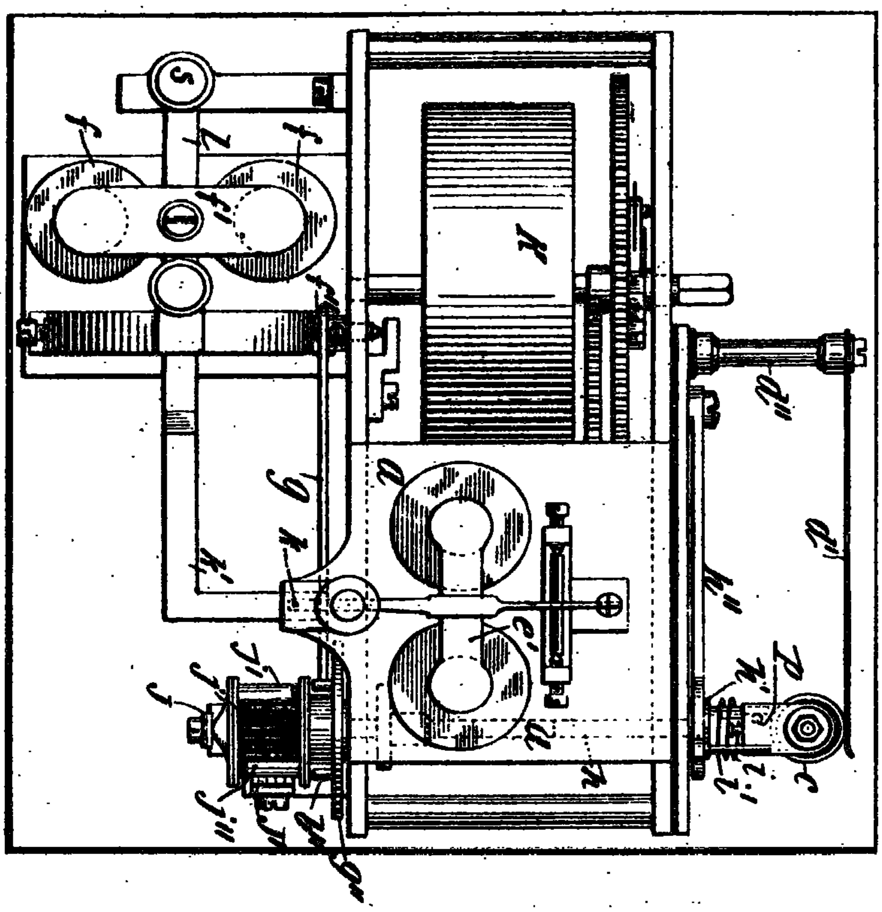
Fig. 4.



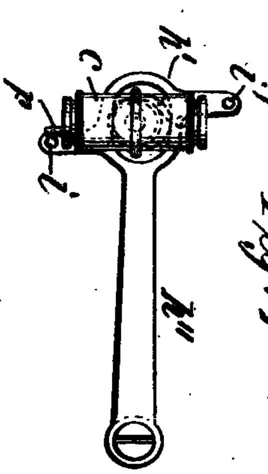


Fig. 7.

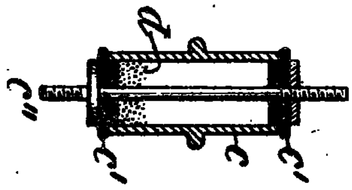
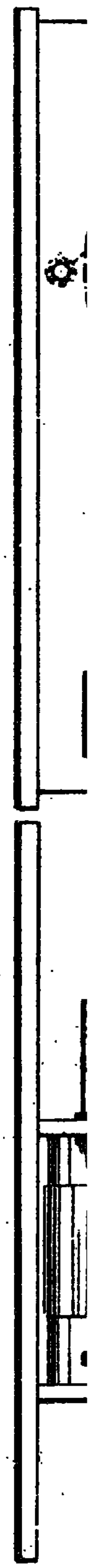


Fig. 8.



[This Drawing is a reproduction of the Original on a reduced scale]

Fig. 5

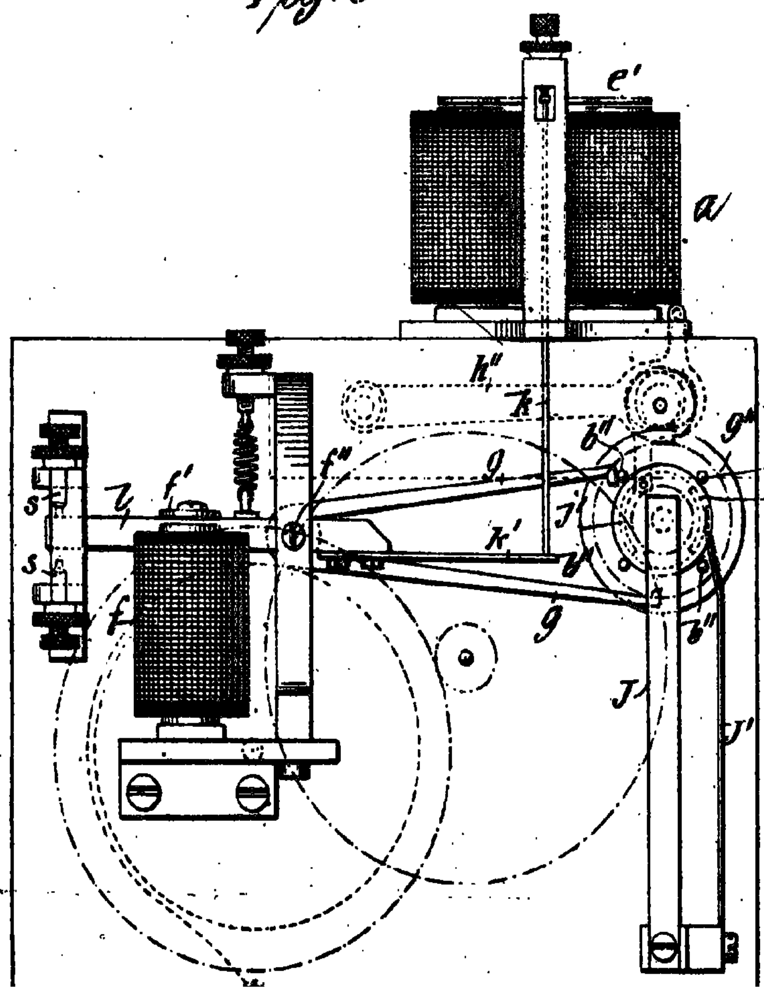
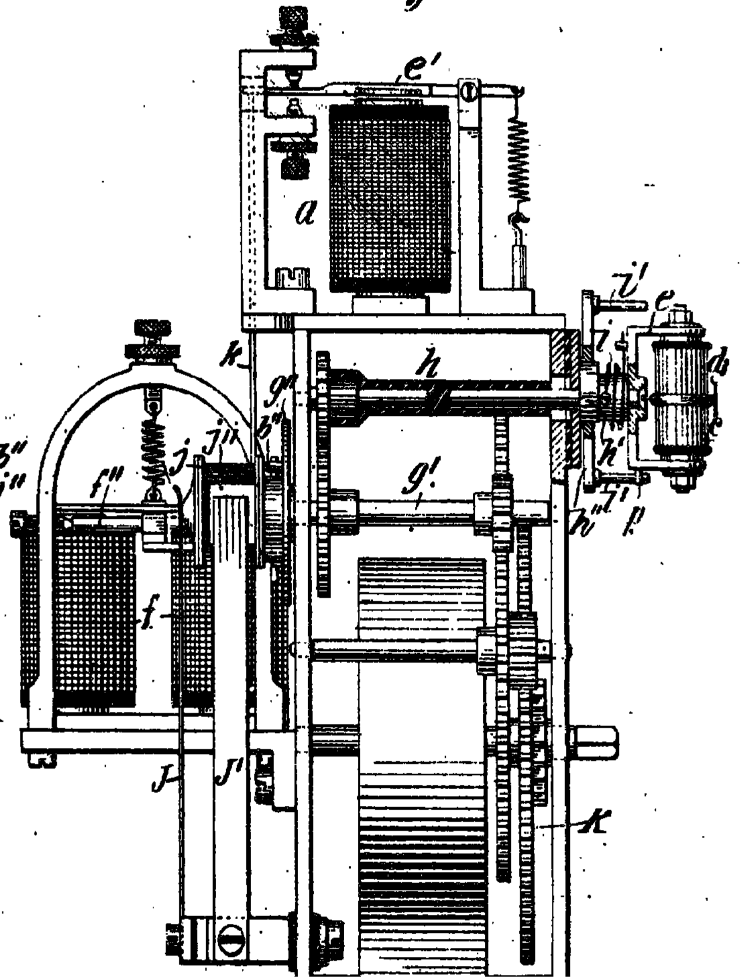


Fig. 6



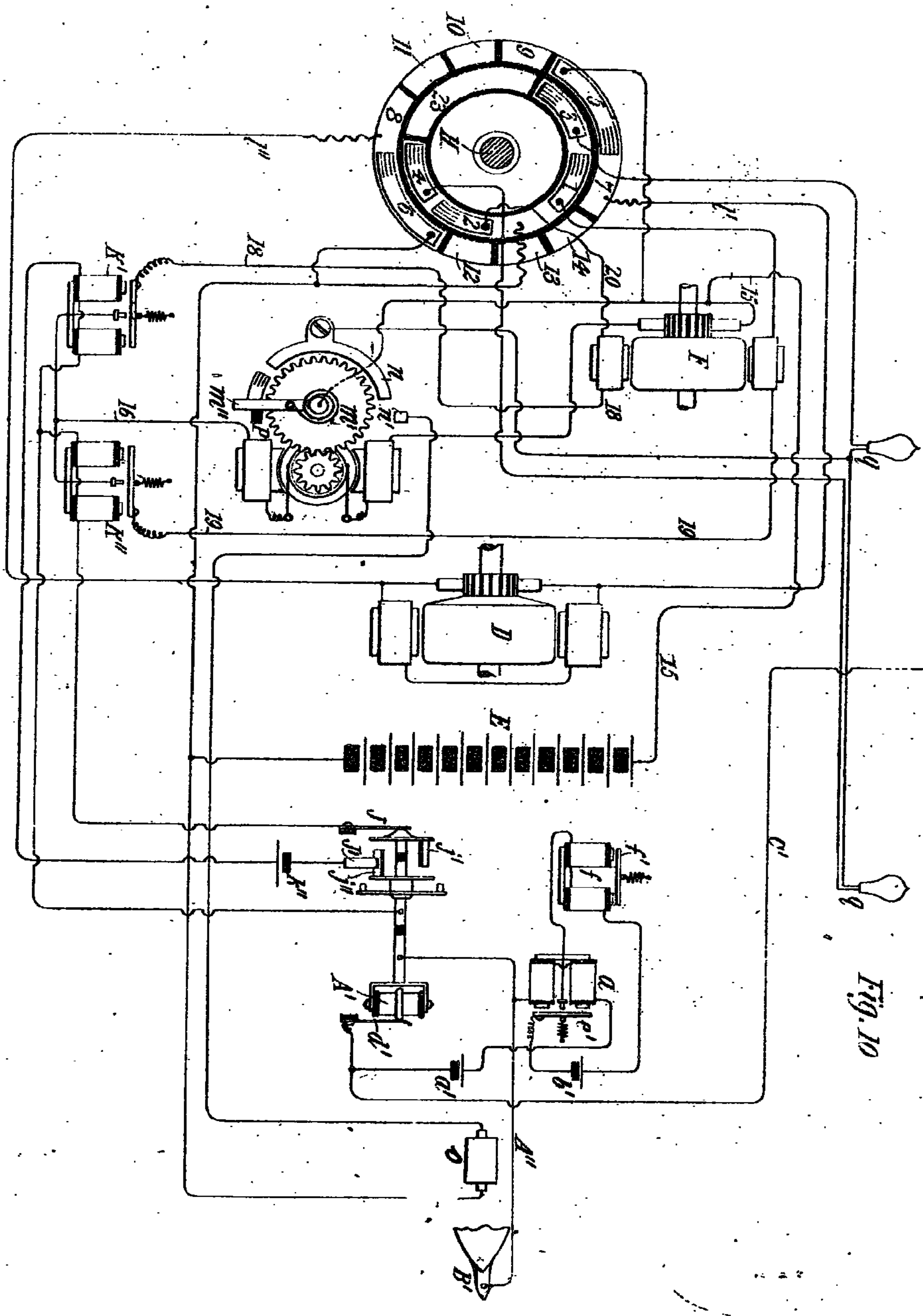


Fig. 10

[This Drawing is a reproduction of the Original on a reduced scale.]

Malby & Sons, Photo-Litho.

[Second Edition.]

PATENT SPECIFICATION

Application Date: Apr. 1, 1921. No. 9729/21. **174,544**

Complete Left: Sept. 2, 1921.

Complete Accepted: Feb. 2, 1922.

PROVISIONAL SPECIFICATION.

Improvements in Methods of and Apparatus for the Generation of Power by Elastic Fluid Turbines.

I, NIKOLA TESLA, Mechanical and Electrical Engineer, citizen of the United States of America, of 8, West 40th Street, New York City, U.S.A., do hereby declare the nature of this invention to be as follows:—

In the transformation of the heat of elastic media, by means of turbines, two methods are now extensively employed. In one, the working fluid is expanded through a stationary nozzle and the free jet, impinging against vanes or equivalent devices integral with the rotor, gives up to it velocity energy, thus setting it in motion by action. In the other, the fluid is admitted at full pressure to curved blades or channels in the rotor where it expands imparting energy to the same and causing it to turn by reaction. For well-known technical reasons turbines operating purely on either the first or the second principle are scarcely ever used, both processes being jointly applied in modern machines. Furthermore, almost invariably staging is resorted to with the object of subdividing the velocity- and pressure-drop and improving thereby the performance in conformity with fundamental laws of propulsion.

As is obvious from theoretical considerations and heat diagrams, the reaction turbine with pressure stages is generally capable of a higher thermodynamic efficiency because it has a bigger "reheat factor", that is to say, it transforms into mechanical effort a considerably larger portion of friction heat than recovered in the action turbine, with velocity stages. On the other hand, it will be equally apparent that the former is more limited in the temperature range and, in view of this handicap, its superiority would not be so pronounced were it not for the fact that the relative velocity of the fluid is greater in the latter turbine, this detracting still more from its efficiency.

These respective qualities and shortcomings have been fully recognized by engineers long ago and have gradually led to the employment of impulse- and reaction-wheels merged into one unit which is thus better adapted for meeting the requirements and should be more economical. But although this idea seems sound, the temperature range has not been very much increased through its application and the gain, so far effected, is moderate indeed, to the point of being doubtful in many instances. Definite limits to progress in this direction have been reached in the existing commercial apparatus and the discovery of other ways and means for saving fuel and reducing the cost of installment and operation has become a problem rendered especially pressing throughout the world by the greatly increased cost of this commodity.

The advantages of the action and reaction principles can be more completely realized through a process which constitutes my present invention and, briefly stated, consists in deriving motive power from the heat of an elastic medium first by means of friction and then by reaction. The best instrumentalities for the purpose, of which I am aware, are a turbine of the kind described in my British Patent No. 24,001 of 1910 and one of the Parsons type, both being connected or worked independently. The fluid is admitted to my turbine through a suitable nozzle which may be expanding, straight or converging, and in traversing the spaces between the disks exercises a frictional drag, thus transforming a part of the available heat into mechanical work. Upon exhausting under proper temperature and pressure conditions it is passed through the Parsons turbine in which another portion of its caloric energy is usefully converted by reaction. Careful scientific investigation, supported by experiment, has shown that important economic results can be secured by the new method and that this particular combination of apparatus possesses features of unusual merit.

In the first place my turbine is exceedingly suited for very elevated temperatures and also high pressures, while the Parsons excels in the efficiency of the thermo-dynamic transformation at moderate temperatures and low pressures. Again, the former permits the fluid to be expanded either in the nozzle, the rotor or both, and this flexibility facilitates the establishment and maintenance of pressure and temperature conditions favorable to both turbines, thus enhancing economy. Their combination is, however, of quite exceptional value in cases when reversible units are indispensable, as on shipboard, where it provides a simpler, more efficient and far more effective apparatus for forward propulsion as well as backing, my turbine being much better adapted for reversing purposes than other forms with small clearances and delicate blading easily damaged.

While my turbine will yield the best results in co-operation with the Parsons it is eminently qualified to serve as first stage, or stages, in conjunction with other types of turbines, of whatever kind, also with rotating and reciprocating engines, and in this broader sense my improved process may be defined as one in which the available heat of an elastic medium is usefully transformed first by friction, as indicated, and then by action or reaction.

Dated this 31st day of March, 1921.

NIKOLA TESLA.

COMPLETE SPECIFICATION.

Improvements in Methods of and Apparatus for the Generation of Power by Elastic Fluid Turbines.

I, Nikola Tesla, Electrical and Mechanical Engineer, citizen of the United States of America, of 8, West 40th Street, New York, N.Y., U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In the transformation of the heat energy of elastic media, by means of turbines, two methods are now extensively employed. In one, the working fluid is expanded through a stationary nozzle and the free jet, impinging against vanes or equivalent devices integral with the rotor, gives up to it velocity energy, thus setting it in motion by action. In the other, the fluid is admitted at full pressure to curved blades or channels in the rotor where it expands imparting energy to the same and causing it to turn by reaction. For well-known technical reasons turbines operating purely on either the first or the second principle are scarcely ever used, both processes being jointly applied in modern machines. Furthermore, almost invariably staging is resorted to with the object of subdividing the velocity- and pressure-drop and improving thereby the performance in conformity with fundamental laws of propulsion.

As is obvious from theoretical consideration and heat diagrams, the reaction turbine with pressure stages is generally capable of a higher thermo-dynamic efficiency because it has a bigger "reheat factor", that is to say, it transforms into mechanical effort a considerably larger portion of friction heat than is recovered in the action turbine, with velocity stages. On the other hand, it will be equally apparent that the former is more limited in the temperature range and, in view of this handicap, its superiority would not be so pronounced were it not for the fact that usually the relative velocity of the fluid is greater in the latter turbine, this detracting still more from its efficiency.

These respective qualities and shortcomings have been long recognized by engineers and have gradually led to the employment of impulse and reaction-wheels merged into one unit which is thus better adapted for meeting the requirements and should be more economical. But although this idea seems sound, the temperature range has not been very much increased through its application and the gain, so far effected, is moderate indeed, to the point of being doubtful in many instances. Definite limits to progress in this direction have been reached in the existing commercial apparatus and the discovery of other ways and means for saving fuel and reducing the cost of installation has become a problem rendered especially pressing throughout the world by the greatly increased cost of this commodity.

The economic advantages contemplated can be more completely realized through a process which constitutes my present invention and, briefly stated, consists in converting part of the heat energy of an elastic medium into mechanical work by friction, preferably at a high temperature, and a further part by action or reaction at a lower temperature. The best instrumentalities for the purpose, of which I am aware, are a friction turbine of the kind described in my British Patent No. 24,001 of 1910 and one of the reaction type, such as the Parsons, both being connected or worked independently. The fluid is admitted to my turbine through a suitable nozzle which may be expanding, straight or converging, and in traversing the spaces between the discs exercises a frictional drag, thus transforming a part of the available heat energy into mechanical work. Upon exhausting under proper temperature and pressure conditions it is passed through the reaction turbine in which another portion of its caloric energy is usefully converted by reaction.

In the accompanying drawings Fig. 1 is intended to represent my improved turbine and one of the Parsons type operatively joined and with their shafts flexibly connected; Fig. 2 is a plan view of the same with supply conduits and inlet valves, and Fig. 3 a vertical cross-section of my turbine.

Referring to the figures, 1 illustrates the rotor of my turbine enclosed in a casing 2, 2, provided with two inlets 3, 3 for the working medium, nozzles 4 and 5 —one for normal operation and the other for reversal—and two exhaust openings 6, 6 which lead through a conduit 7 to the intake 8 and slide valve 9 of the Parsons turbine 10. The exhaust 11 of the latter communicates through a conduit 12 with the condenser to which is also connected a by-pass 13, branching out from exhaust pipe 7 and equipped with a valve 14. A throttle valve 15 controls the admission of the elastic fluid to my turbine which has, besides, two suitable valves 16 and 17, preferably joined by mechanical means as chain 18, enabling them to be turned together so that one will be closed tight while the other is wide open.

In normal operation valves 17 and 14 are closed and the medium is admitted to my turbine through valves 15, 16 and nozzle 4, whence it passes through the rotor 1, exhaust openings 6, 6 and pipe 7 to the intake 8 and valve 9 of the Parsons turbine 10 and, after traversing the same, is discharged through exhaust 11 and conduit 12 into the condenser, under which conditions both the turbines are actuated in the same direction, rotation taking place in the sense of the solid arrow Fig. 3. When it is desired to operate in the reverse direction (indicated by the dotted arrow), valves 16 and 9 are closed and 17 and 14 opened wide, the medium entering my turbine through nozzle 5, and after passing through the rotor 1, exhaust openings 6, 6, pipe 7 and by-pass 13, discharges into the condenser. The Parsons turbine is then driven in a direction opposite to its blading but offers a relatively small resistance owing to the vacuum therein; my turbine, on the other hand, develops an amount of power much greater than when working as first described on account of its direct connection with the condenser and correspondingly increased heat drop.

Careful scientific investigation, supported by experiment, has shown that important economic results can be secured by the new method and that this particular combination of apparatus possesses features of unusual merit.

In the first place my turbine is especially suited for very elevated temperatures and also high pressures, while the Parsons is particularly adapted to thermo-dynamic transformation at moderate temperatures and low pressures. Again, the former permits the fluid to be expanded either in the nozzle, the rotor or both, and this flexibility facilitates the establishment and maintenance of pressure and temperature conditions favorable to both turbines, thus enhancing economy. Their combination is, however, of quite exceptional value in cases when reversible units are indispensable, as on shipboard, where it provides a simpler and more effective apparatus for forward propulsion as well as backing, my turbine being much more dependable than the present forms with buckets and blades which are very liable to deterioration and easily damaged.

In the use of different types, as here contemplated, the individual heat drops in them may be considerably varied in magnitude, but to give a practical example I would say that very good results, when working with superheated steam alone, are obtainable by admitting the steam to the nozzle of the friction turbine at about 1100° F. and exhausting it at approximately 550° F. into a reaction turbine capable of operating safely at that temperature.

While my turbine in such combinations will yield the best results in co-operation with the Parsons, it is eminently qualified to serve as first stage, or stages, in conjunction with other types of turbines, of whatever kind; also with rotary and reciprocating engines, and in this broader sense my improved process may be defined as one in which the available heat energy of an elastic fluid is usefully transformed first by friction, as indicated, and then by action or reaction.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is :—

1. The improved method of thermodynamic transformation which consists in converting a part of the heat energy of an elastic fluid by disc friction and a further part by blade action, substantially as described.

2. The hereinbefore described process of transforming the heat energy of an elastic fluid into rotary mechanical work which consists in converting a part of the energy of the fluid by friction at high temperature and a further part by action and/or reaction at a lower temperature, substantially as described.

3. In the conversion of heat energy of elastic fluids the combination of the friction and reaction type of turbine, as described.

4. The combined use of a friction turbine of the kind described with an action and reaction engine in the transformation of the heat energy of elastic fluids into mechanical work.

5. The combination of a friction turbine of the type described with a turbine of the reaction type mounted on the same shaft or on connected shafts to form an operative unit for the transformation of the heat energy of elastic fluids into mechanical work.

6. The combination of a friction and a reaction turbine of the types described connected to form a power unit so that both may operate together in one direction or be driven in the opposite direction by the friction turbine, the reaction turbine running idle, as described.

Dated the 23rd day of August, 1921.

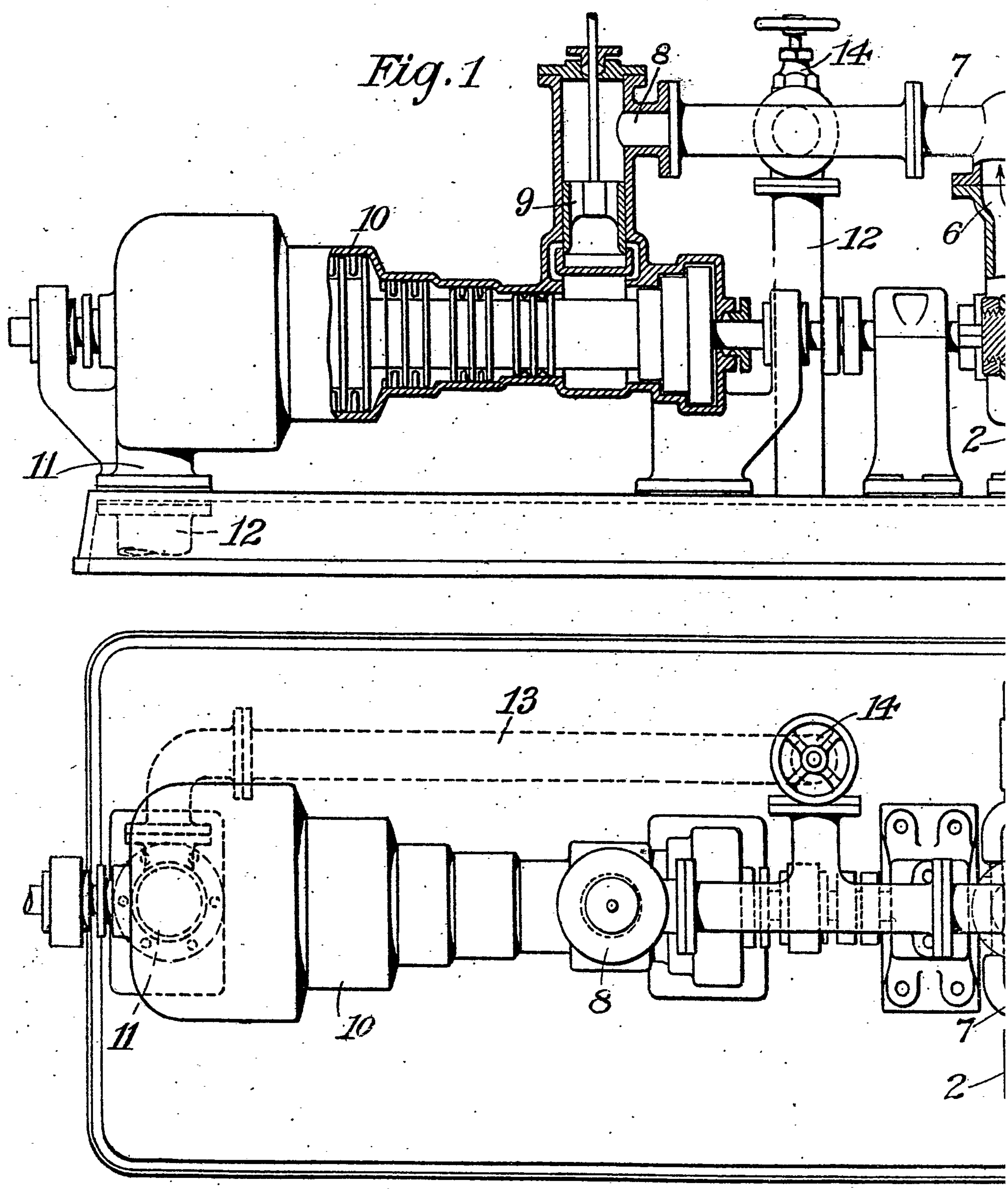
NIKOLA TESLA.

Hereford: Printed for His Majesty's Stationery Office, by The Hereford Times Ltd.
[Wt. 70—125/10/1923.]

2nd Edition

[This Drawing is a full-size reproduction of the Original.]

Fig. 1



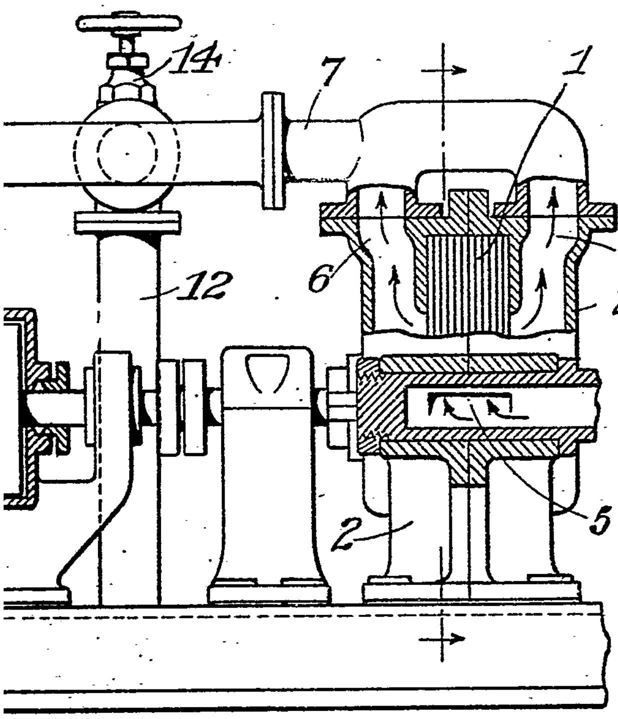


Fig. 3

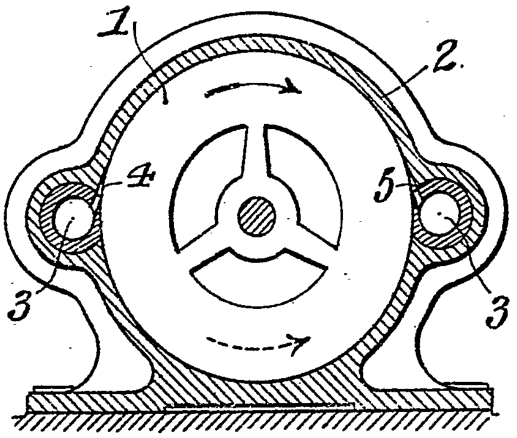
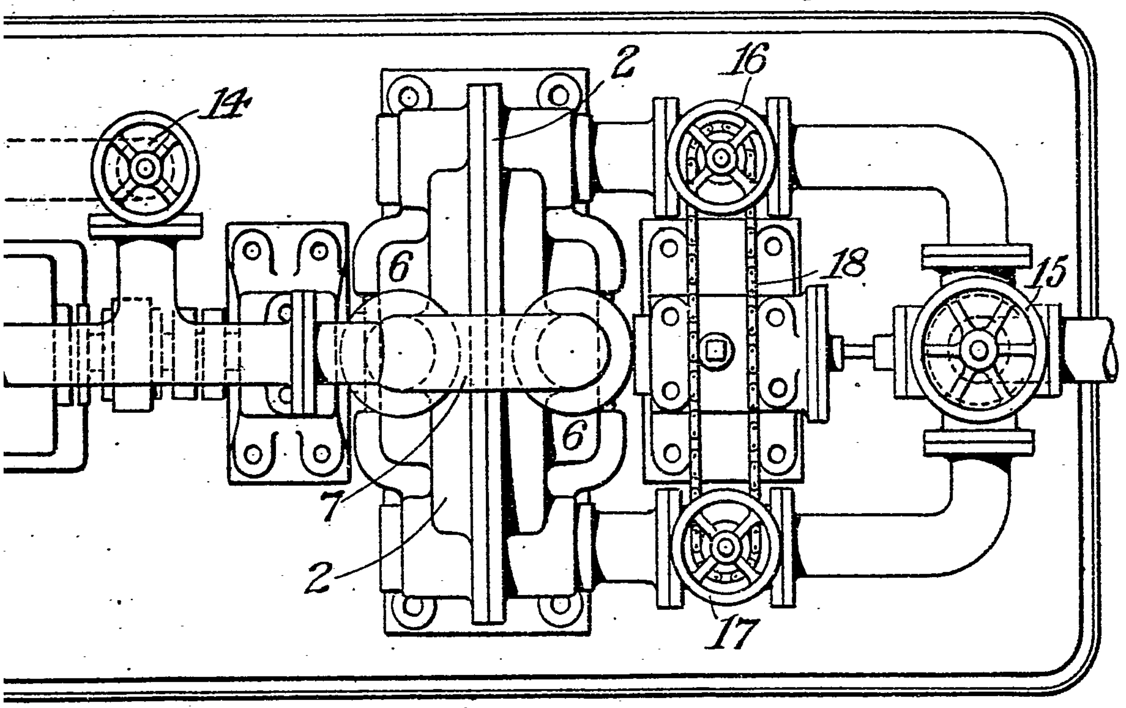


Fig. 2



2nd Edition

Fig. 1

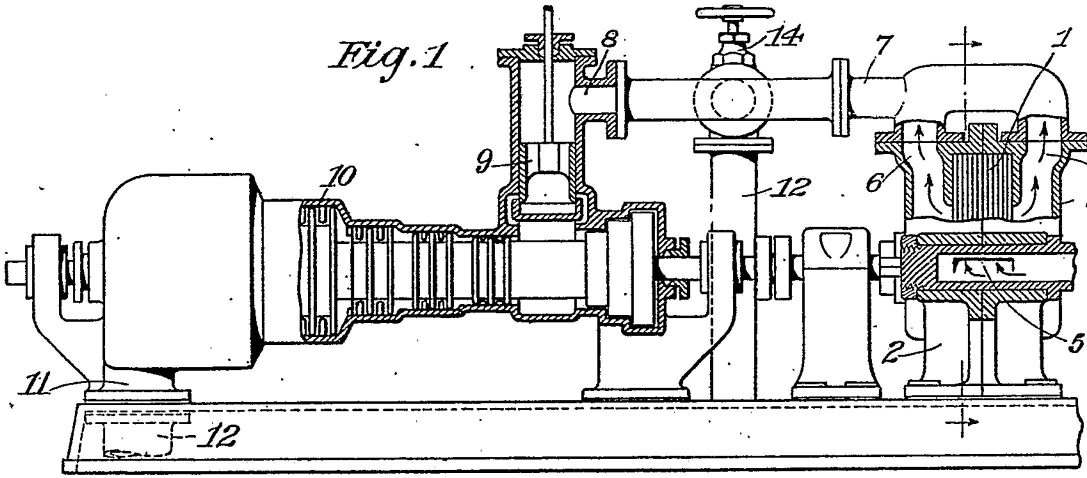


Fig. 3

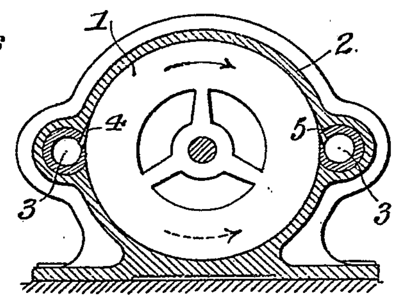
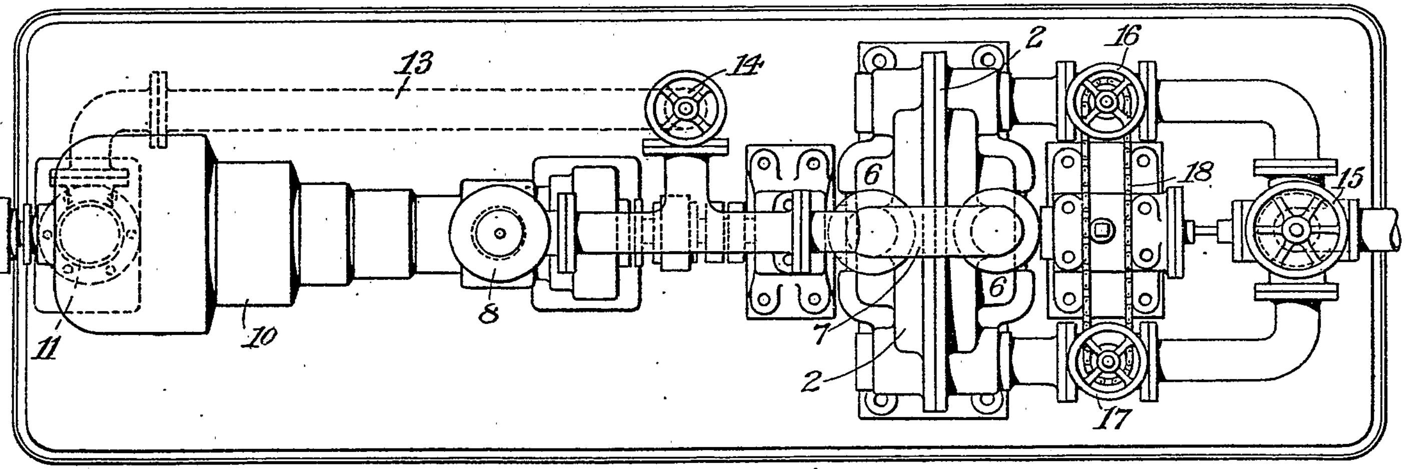


Fig. 2



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PATENT SPECIFICATION

179,043

Application Date: Mar. 24, 1921. No. 9098/21.

Complete Left: Sept. 5, 1921.

Complete Accepted: May 4, 1922.

PROVISIONAL SPECIFICATION.

Improved Process of and Apparatus for Production of High Vacua.

I, NIKOLA TESLA, Mechanical and Electrical Engineer, citizen of the United States of America, of 8, West 40th Street, New York City, U.S.A., do hereby declare the nature of this invention to be as follows:—

In the development of power by thermodynamic primemovers, as steam engines and turbines, a low back pressure is essential to good economy, the performance of the machine being increased from fifty to one hundred *per cent.* by reducing the absolute pressure in the exhaust space from fifteen to about one pound per square inch. Turbines are particularly susceptible to such improvement and in their use for operation of power plants and manufacturing establishments the attainment and steady maintenance of high vacua has assumed great importance, every effort being made to better the conditions in this respect. The gain effected by this means is, in a large measure, dependent on the initial pressure, characteristics of the primemover, temperature of the cooling medium, cost of the condensing apparatus and many other things which are all well-known to experts. The theoretical saving of from five to six *per cent.* of fuel for each additional inch of vacuum is often closely approximated in modern installations, but the economic advantages are appreciably lessened when higher vacua are applied to existing machines purposely designed to operate with lower ones. More especially is this true of a turbine in which the reduction of back pressure merely increases the velocity of exit of the vapors without materially augmenting the speed of their impact against the vanes, buckets, or equivalent organs, when the loss of kinetic energy in the exhaust may offset a considerable portion of the useful work. In such cases some constructional changes in the turbine and auxiliaries may have to be made in order to secure the results here contemplated but the additional capital used for this purpose will be profitably invested. Summing up the situation it may be generally stated that a more or less substantial reduction of fuel cost can be made in most of the existing power plants by the adoption of proper pumping apparatus and establishment of working conditions nearly corresponding to those of an ideal condenser.

The chief difficulties which have thus far retarded advancement in this direction are encountered in the enormous volumes of the air and vapor at very low pressures as well as unavoidable leaks in the condenser, pipe joints, valves, glands and stuffing boxes. At present exhaustion is usually accomplished by reciprocating pumps and these, on account of the necessarily low speed of the pistons are large and, moreover, incapable of satisfactory performance in the presence of big leaks. As a direct result of this the condensing plant is both bulky and expensive and, worse still, its size and cost increase entirely in disproportion to the results attained. To illustrate—the outlay involved in the instalment of condensing apparatus for a twenty-eight inch vacuum is more than double that required for a vacuum of twenty-six inches and these draw-backs are still more emphasized with the further reduction of the back pressure. Rotary pumps and jets of water and steam are also used in the production of vacua, but without marked qualitative advantages. As to the possible employment of multi-stage centrifugal exhausters, engineers are still in doubt. Such machines have heretofore served only for purposes of compression and it is more than probable that they would prove unsuitable for very high rarefaction. The introduction of Sir Charles Parsons' "vacuum augmentor" and Weir's "dry air" pump was a decided progress towards the desired goal, nevertheless this important problem has only been partially solved and to this day the condensing apparatus is admittedly the most troublesome part of the whole power mechanism, to such an extent, indeed, that its duplication is often deemed advisable if not absolutely necessary to the safe and reliable working of the plant.

I have achieved better success in departing from the customary method of removing the air and entrained steam from the condenser by bodily carriers as jets, reciprocating pistons or rotating vanes, and availing myself of the properties of adhesion and viscosity which, according to experimental evidence, are retained by the gases and vapors even at very high degrees of attenuation. The new process which I have thus evolved is rendered practicable through a novel type of pump which I have invented and described in my British Patent No. 24,001 of 1910. This device, suitably modified in certain details of construction and run at the excessive peripheral speed of which an unloaded system is capable, exhibits two remarkable and valuable properties. One of these is to expel the rarefied fluids at such an immense rate that a hole of some size can be drilled in the condenser without much effect on the vacuum gauge. The other is to draw out the fluids until the exhaustion is almost complete. A machine of this kind, constructed in stages, is alone sufficient for the production of extremely high vacua and I believe this quality to be very valuable inasmuch as it is not possessed to such a degree by other types of commercial pumps which have come to my knowledge. However, in order to avoid undue complication and expense I make use of the ordinary exhausting apparatus and simply insert between it and the condenser my pump, which sucks out the highly attenuated media, compresses and delivers them to the "dry air" or other pump. This combination is especially advantageous from the practical point of view as good results can be secured with a single stage and the instalment of my device calls for but a slight change in the steam plant. The benefits derived are twofold: a higher vacuum is attained and, what is perhaps more important, the frequent and unavoidable impairments of the same, which seriously affect the economy, are virtually eliminated. My pump makes possible the maintenance of high vacua even when the percentage of air or other fluids carried with the steam is very great and on this account should prove particularly useful in the operation of mixed fluid turbines.

Dated this 24th day of March, 1921.

NIKOLA TESLA.

COMPLETE SPECIFICATION.

Improved Process of and Apparatus for Production of High Vacua.

I, Nikola Tesla, Electrical and Mechanical Engineer, citizen of United States of America, of No. 8, West 40th Street, New York, N.Y., U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In the development of power by thermodynamic primemovers, as steam engines and turbines, a low back pressure is essential to good economy, the performance of the machine being increased from fifty to one hundred *per cent.* by reducing the absolute pressure in the exhaust space from fifteen to about one pound per square inch. Turbines are particularly susceptible to such improvement and in their use for operation of power plants and manufacturing establishments the attainment and steady maintenance of high vacua has assumed great importance, every effort being made to better the conditions in this respect. The gain effected by this means is, in a large measure, dependent on the initial pressure, characteristics of the primemover, temperature of the cooling medium, cost of the condensing apparatus and many other things which are all well-known to experts. The theoretical saving of from five to six *per cent.* of fuel for each additional inch of vacuum is often closely approximated in modern installations, but the economic advantages are appreciably lessened when higher vacua are applied to existing machines purposely designed to operate with lower ones. More especially is this true of a turbine in which the reduction of back pressure merely increases the velocity of exit of the vapors without materially augmenting the speed of their impact against the vanes, buckets, or equivalent organs, when the loss of kinetic energy in the exhaust may offset a considerable portion of the useful work. In such cases some constructional changes in the turbine and auxiliaries may have to be made in order to secure the results here contemplated but the additional capital used for this purpose will be profitably invested. Summing up the situation it may be generally stated that a more or less substantial reduction of fuel cost can be made in most of the existing power plants by the adoption of proper pumping apparatus and establishment of working conditions nearly corresponding to those of an ideal condenser.

The chief difficulties which have thus far retarded advancement in this direction are encountered in the enormous volumes of the air and vapor at very low pressures as well as unavoidable leaks in the condenser, pipe joints, valves, glands and stuffing boxes. At present exhaustion is usually accomplished by reciprocating pumps and these, on account of the necessarily low speed of the pistons are large and, moreover, incapable of satisfactory performance in the presence of big leaks. As a direct result of this the condensing plant is both bulky and expensive and, worse still, its size and cost increase entirely in disproportion to the results attained. To illustrate—the outlay involved in the instalment of condensing apparatus for a twenty-eight inch vacuum is more than double that required for a vacuum of twenty-six inches and these draw-backs are still more emphasized with the further reduction of the back pressure. Rotary pumps and jets of water and steam are also used in the production of vacua, but without marked qualitative advantages.

I have achieved better success in departing from the customary method of removing the air and entrained steam from the condenser by bodily carriers as jets, reciprocating pistons or rotating vanes, and availing myself of the properties of adhesion and viscosity which, according to experimental evidence are retained by the gases and vapors even at very high degrees of attenuation. This new process is rendered practicable through a pump, the underlying principle of which is fully explained in my British Patent 24,001 of 1910, but which is modified as hereinafter described and when run at the very great peripheral speed of which an unloaded system is capable, exhibits two remarkable and valuable properties. One of these is to expel the rarefied fluids at such an immense rate that a hole of some size can be drilled in the condenser without much effect on the vacuum gauge. The other is to draw out the fluids until the exhaustion is almost complete. A machine of this kind, constructed in stages, is alone sufficient for the production of extremely high vacua and I believe this quality to be very valuable inasmuch as it is not possessed to such a degree by other types of commercial pumps which have come to my knowledge. I have also found that a very effective combination is produced by inserting my pump between the condenser and a "dry air" or other pump. This combination is especially advantageous from the practical point of view as good results can be secured with a single stage and the instalment of my device calls for but a slight change in the steam plant. The benefits derived are twofold; a higher vacuum is attained and, what is perhaps more important, the frequent and unavoidable impairments of the same, which seriously affect the economy, are virtually eliminated. My pump makes possible the maintenance of high vacua even when the percentage of air or other fluids carried with the steam is very great and on this account should prove particularly useful in the operation of mixed fluid turbines.

My invention will be more fully understood by reference to the accompanying drawings in which Fig. 1 shows a multi-stage pump of this kind in sectional views, and Fig. 2 illustrates its use in connection with a double-acting reciprocating pump.

In the first figure, 1, 2, . . . are rotors each of which, as 1, comprises a number of relatively thin disks 3, 3 . . . separated by starwashers 4, 4 . . . and held together by rigid end-plates 5 and 6 on a sleeve 7 which is fitted and keyed to a shaft 8, rotatably supported in bearings 9, 9. The rotors are contained in separate chambers of a common structure 10 which surrounds them and is made up of parts held together by flange connections. Beginning with the fist stage at 1, the rotors diminish in width, each following being made narrower than the preceding, for obvious economic reasons. All the thin discs, as 3, 3 . . . , and lefthand end-plates, as 5, are provided with the usual central openings, but the righthand end-plates, as 6, are blank. The individual chambers, containing the rotors, communicate with each other through channels, as 11, extending from the peripheral region of one to the central part of the next, so that the fluids aspired at the intakes 12, 12 are compelled to pass through the whole series of rotors and are finally ejected at the flanged opening 13 of the last chamber. In order to reduce leakage along the shaft, close-fitting joints or locks, as 14, are employed which may be of ordinary construction and need not be dwelled upon specifically. The number of stages will depend on the peripheral velocity and the degree of exhaustion which it is desired to secure, and in extreme cases a number of separate structures, with intermediate bearings for the shaft, may have to be provided. When found preferable the pump may be of the double-flow type, when there will be no appreciable side thrust, otherwise provision for taking it up shoulde be made.

The modifications in details of construction, to which reference has been made, consist in the employment of smaller spaces between the discs than has hitherto been the case, and of close side-clearances. To give a practical example, I may state that spaces of $^3/_{64}$ of an inch will be effective in the production of very high vacua with discs of, say, 24 inches in diameter. I also make all discs tapering, when necessary, in order to operate safely at an extremely high peripheral velocity which is very desirable since it reflects both on the size of the machine and its effectiveness.

The arrangement represented diagrammatically in Fig. 2 is especially suitable and advantageous in connection with existing steam plants operating with high vacuum and permits the carrying out of my improvements in a simple manner and at comparatively small cost. In this case my pump, which may have but one rotor of the above description, is connected with its intake 12, through a pipe 15, to the top of a condenser 16, and with its discharge opening 13, by pipe 17, to the suction duct of a reciprocating dry air pump 18. It goes without saying that in actual practice connections 15 and 17 will be short mains of very large section as the volume of fluids to be pumped may be enormous.

The operation will be readily understood from the foregoing. The intakes 12 (Fig. 1) being joined by an air-tight connection to the vessel to be exhausted and the system of discs run at very high peripheral velocity the fluids, by reason of their properties of viscosity and adhesion, are drawn out of the vessel until the degree of rarefaction is attained for which the apparatus has been designed. In their passage through the series of rotors the fluids are compressed by stages and ejected through the opening 13 at a volume greatly reduced. The vacuum produced by this means may be extremely high because of the apparently unique properties of the device pointed out before, and as the fluids, irrespective of their density, are sucked out at an excessive speed, leaks through the glands, stuffing boxes and connections are of but slight effect.

In the arrangement shown in Fig. 2 my pump serves to evacuate the condenser much more effectively and by compressing the fluids at the intake of the reciprocating pump improves the performance of the same. The instalment of the device in existing plants does not call for extensive alterations in the same and will result in a notable saving of fuel. My pump may also be advantageously employed in place of a steam jet in conjunction with a small condenser in which case it will be of insignificant dimensions and economical in steam consumption.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The improved process of rarefaction which consists in rotating a disc system communicating with a receptacle and continuously ejecting fluid adhering to said system, until a high vacuum is attained in the receptacle, as described.

2. The improved method of exhausting a vessel which consists in rotating a system of discs and continuously applying the frictional force, arising from the

viscosity of the fluid and its adhesion to said system, to exhaust the vessel until a high vacuum is attained, substantially as described.

3. The improved process of rarefaction which consists in sucking out of a vessel attenuated fluids by the frictional force of a system of rotating discs, compressing them in the passage through the same, and discharging them into the intake duct of a positively acting pump, as described.

4. As a means for obtaining high vacua, the combination of apparatus, as illustrated and described.

Dated the 23rd day of August, 1921.

NIKOLA TESLA.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1922.

[This Drawing is a reproduction of the Original on a reduced scale]

Fig. 1

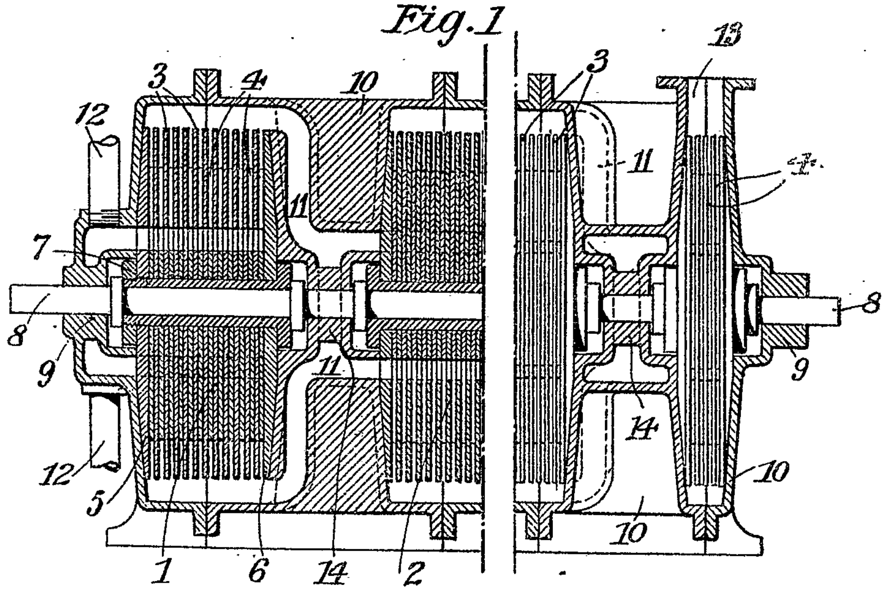
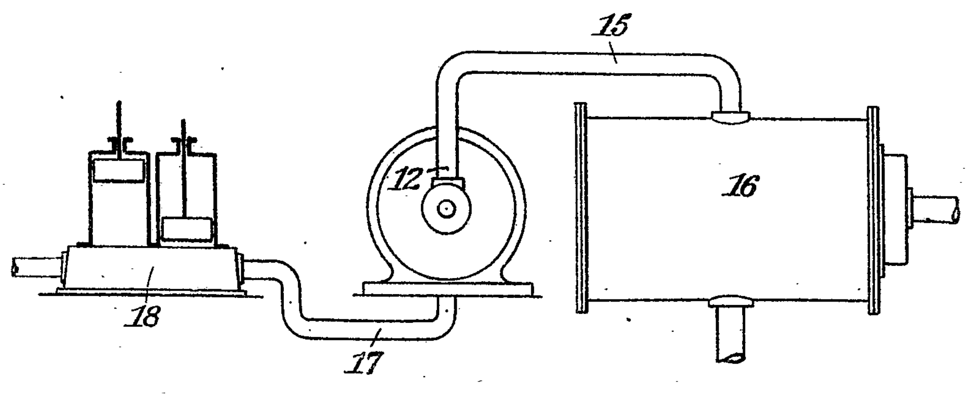


Fig. 2



PATENT SPECIFICATION

Application Date: Apr. 4, 1921. No. 9961/21. **185,446**

Complete Left: Sept. 5, 1921.

Complete Accepted: Sept. 4, 1922.

PROVISIONAL SPECIFICATION.

Method of and Apparatus for Aerial Transportation.

I, NIKOLA TESLA, Mechanical and Electrical Engineer, citizen of the United States of America, of 8, West 40 Street, New York City, U.S.A., do hereby declare the nature of this invention to be as follows:—

The utility of the aeroplane as a means of transport is materially lessened and its commercial introduction greatly hampered owing to the inherent inability of the mechanism to readily rise and alight, which is an unavoidable consequence of the fact that the required lifting force can only be produced by a more or less rapid translatory movement of the planes or foils. In actual experience the minimum speed for ascension and landing is a considerable fraction of that in full flight, and the principles of design do not admit of a very great advance in this respect without sacrifice of some desirable features. For this reason planes of very large area, high lift wing-sections, deflectors of the slipstream of the propeller, or analogous means, which might be helpful in these operations, do not afford the remedy sought. This indispensable high velocity, imperilling life and property, makes it necessary to equip the machine with special appliances and provide suitable facilities at the terminals of the route, all of which entail numerous drawbacks and difficulties of a serious nature. So imperative has it become to discover some way of doing away with these limitations of the aeroplane that the consensus of expert opinion characterizes the problem as one of the most pressing and important and its practical solution is eagerly awaited by those engaged in the development of the art, as well as the general public.

Many attempts have been made to this end, mostly based on the use of independent devices for the express purpose of facilitating and insuring the start and finish of the aerial journey, but the operativeness of the arrangements proposed is not conclusively demonstrated and, besides, they are objectionable, constructively or otherwise, to such an extent that builders of commercial apparatus have so far not considered them of sufficient value to depart from present practice.

More recently, professional attention has been turned to the helicopter which is devoid of planes as distinct organs of support and, presumably, enables both vertical and horizontal propulsion to be satisfactorily accomplished through the instrumentality of the propeller alone. However, although this idea is quite old and not a few experts have endeavored to carry it out in various ways, no success has as yet been achieved. Evidently, this is due to the inadequacy of the engines employed and, perhaps, also to certain heretofore unsuspected characteristics of the device and fallacies in the accepted theory of its operation, an elucidation of which is deemed necessary for the clear understanding of the subject.

The prospects of a flying machine of this kind appear at first attractive, primarily because it makes possible the carrying of great loads with a relatively small expenditure of energy. This follows directly from the fundamental laws of fluid propulsion, laid down by W. T. M. Rankine more than fifty years ago, in conformity with which the thrust is equal to the integral sum of the products of the masses and velocities of the projected air particles; symbolically expressed,

$$T = \Sigma (mv).$$

On the other hand, the kinetic energy of the air set in motion is

$$E = \Sigma (\tfrac{1}{2}mv^2).$$

From these equations it is evident that a great thrust can be obtained with a comparatively small amount of power simply by increasing the aggregate mass of the particles and reducing their velocities. Taking a special case for illustration, if the thrust under given conditions be ten pounds per horsepower, then a hundredfold increase of the mass of air, accompanied by a reduction of its effective velocity to one-tenth, would produce a force of one hundred pounds per horsepower. But the seemingly great gain thus secured is of little significance in aviation, for the reason that a high speed of travel is generally an essential requirement which can not be fulfilled except by propelling the air at high velocity, and that obviously implies a relatively small thrust.

Another quality commonly attributed to the helicopter is great stability, this being, apparently, a logical inference judging from the location of the centers of gravity and pressure. It will be found, though, that contrary to this prevailing opinion the device, while moving in any direction other than up or down, is in an equilibrium easily disturbed and has, moreover, a pronounced tendency to oscillate. It is true, of course, that when the axis of the propeller is vertical and the ambient air quiscent the machine is stable to a degree, but if it is tilted even slightly, or if the medium becomes agitated, such is no longer the case.

In explanation of this and other pecularities, assume the helicopter poised in still air at a certain height, the axial thrust T just equalling the weight, and let the axis of the propeller be inclined to form an angle α with the horizontal. The change to the new position will have a twofold effect: the vertical thrust will be diminished to

$$T_v = T \sin \alpha,$$

and at the same time there will be produced a horizontal thrust

$$T_h = T \cos \alpha.$$

Under the action of the unbalanced force of gravity the machine will now fall along a curve to a level below and if the inclination of the propeller as well as its speed of rotation remain unaltered during the descent, the forces T, T_v and T_h will continuously increase in proportion to the density of the air until the vertical component T_v of the axial thrust T becomes equal to the gravitational attraction. The extent of the drop will be governed by the inclination of the propeller axis and for a given angle it will be, theoretically, the same no matter at what altitude the events take place. To get an idea of its magnitude suppose the elevations of the upper and low strata measured from sea level be h_1 and h_2, respectively, d_1 and d_2 the corresponding air densities and H=26,700 feet the height of the "uniform atmosphere", then as a consequence of Boyle's law the relation will exist

$$h_1 - h_2 = H \log_e \frac{d_2}{d_1}$$

It is evident that $\frac{T}{T_v} = \frac{T}{T} \sin \alpha = \frac{1}{\sin \alpha} = \frac{d_2}{d_1}$ in order that the vertical component of the axial thrust in the lower stratum should just equal the weight. Hence

$$h_1 - h_2 = H \log_e \frac{1}{\sin \alpha}.$$

Taking, in a special case, the angle $\alpha = 60°$, $\frac{1}{\sin \alpha} = \frac{1}{0.866} = 1.1547$ and

$$h_1 - h_2 = 26{,}700 \times \log_e 1.1547 = 3840 \text{ feet}.$$

In reality, the drop will be much greater for the machine, upon reaching the lower layer with a high velocity relative to the medium will be urged further along the path and the kinetic energy, in the vertical sense, possessed by the moving mass must be annihilated before the fall is arrested in a still denser air stratum. At this point the upward thrust will be far in excess of the opposed pull of the weight and the apparatus will rise with first increasing and then diminishing speed to nearly the original height. From there it will again fall and so on, these operations being repeated during the forward flight, the excursions gradually diminishing in magnitude. After a lapse of time, determined by numerous influences, the oscillations should cease altogether and the path described become rectilinear. But this is next to impossible as can be readily shown by pointing out another curious feature of the helicopter.

In the foregoing the axis of the propeller was supposed to move always parallel to itself, which result might be accomplished by the use of an adjustable aileron. In this connection it may be pointed out that such a device will not act in the manner of a rudder, coming into full play at intervals only and performing its functions economically, but will steadily absorb energy, thus occasioning a considerable waste of motive power and adding another to the many disadvantages of the helicopter.

Let now the machine be possessed of a certain degree of freedom, as will be the case normally, and observe in the first place that the blades of the propeller themselves constitute planes developing a reaction thrust, the pressure on the lower leading blade being greater than that exerted on the higher one owing to the compression of the air by the body of the machine and increased density in that region. This thrust, tending to diminish the angle a, will obviously vary during one revolution, being maximum in a position when the line of symmetry of the two propeller blades and that of flight are in a vertical plane and minimum at right angles to it; nevertheless, when the horizontal speed is great it may be considerable and sufficient to quickly overcome the inertia and gyroscopic resistances. Moreover, this disturbing effect partakes of the regenerative quality, the force increasing as the angle a diminishes up to a maximum for $a=45°$. As the axis is tilted more and more, the vertical sustaining effort of the propeller will correspondingly diminish and the machine will fall with a rapidly increasing velocity, finally exceeding the horizontal when the reaction of the blades will be directed upward so as to increase the angle a and thereby cause the machine to soar higher. Thus periodic oscillations, accompanied by ascents and descents, will be set up which may well be magnified to an extent such as to bring about a complete overturn and plunge to earth.

It is held by some experts that the helicopter, because of its smaller body resistance, would be capable of a higher speed than the aeroplane. But this is an erroneous conclusion, contrary to the laws of propulsion. It must be borne in mind that in the former type, the motive power being the same, a greater mass of air must be set in motion with a velocity smaller than in the latter, consequently it must be inferior in speed. But even if the air were propelled in the direction of the axis of the screw with the same speed V in both of them, while the aeroplane can approximate the same, the helicopter could never exceed the horizontal component $V \cos a$ which, under the theoretically most economical conditions of operation, would only be 0.7V.

Another very serious defect of this kind of flying machine, from the practical point of view, is found in the inability of supporting itself in the air in case of failure of the motor, the projected area of the propeller blades being inadequate, for reducing the speed of the fall sufficiently to avoid disaster, and this is a fatal impediment to its commercial use.

From the preceding facts, which are ignored in the technical publications on the subject, it will be clear that the successful solution of the problem is in a different direction.

My invention meets the present necessity in a simple manner without radical departures in construction and sacrifice of valuable features, incidentally securing advantages which should prove very beneficial in the further development of the art. Broadly expressed, it consists in a novel method of transporting bodies through the air in which the machine is raised and lowered solely by the propeller and sustained in its flight by planes. The chief innovations in the mechanism are a prime mover of the kind described in my British Patent No. 24,001 of 1910, a specially designed propeller and arrangements whereby the machine is automatically, or through wilful control, transformed from the helicopter into an aeroplane and *vice versa*.

In the preferred form of design the structure is composed of two planes or foils rigidly joined, their length and distance apart being such as to form a square for the sake of smallness and compactness. With the same object the tail is omitted or, if used, it is retractable. The turbine and other parts of the motive apparatus are placed as in an aeroplane and also the usual controls are provided. At rest the planes are vertical or nearly so and likewise the propeller which is relatively large and built for great strength in order to support safely the entire weight. The seat of the aviator and passengers is suspended on trunnions on which it can turn through an angle of about 90°, springs and cushions being employed to insure and limit its motion through this angle. Hand- and foot-controlled devices are placed so as to be within easy reach of the driver in any position.

At the start, power being turned on, the machine rises vertically in the air to the desired height when it is gradually tilted and becomes an aeroplane, the foils taking up the load as the speed in the horizontal direction increases. In descending, the forward speed is reduced and the machine righted again, becoming a helicopter with the propeller supporting all the load. The turbine referred to is a motor of exceptional lightness and activity and lends itself to this kind of use for which ordinary aviation motors are unsuited. It is capable of carrying a great overload and running without danger at excessive speed so that in the starting and landing operations the necessary power can be developed, even though less efficiently than under normal conditions. However, should the propelling mechanism fail, landing can still be effected without much risk in the usual manner. Such a helicopter-plane constructed as indicated and operated in the manner described, unites the advantages of both types and seems to meet best the requirements of a small, compact, exceedingly speedy and yet very safe machine for commercial use.

Dated this 31st day of March, 1921.

NIKOLA TESLA.

COMPLETE SPECIFICATION.

Method of and Apparatus for Aerial Transportation.

I, Nikola Tesla, Electrical and Mechanical Engineer, citizen of the United States of America, of 8, West 40th Street, New York, N.Y., U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention relates to aerial machines of the kind in which the machine is adapted to be raised and lowered in the manner of a helicopter with the chords of the planes and the axis of the propelling means vertical and in which the planes and propelling means are adapted to be turned through a right angle in the air so that the chords of the planes and the axis of the propelling means are more or less horizontal and the machine can be flown as an aeroplane.

The utility of the aeroplane as a means of transport is materially lessened and its commercial introduction greatly hampered owing to the inherent inability of the mechanism to readily rise and alight, which is an unavoidable consequence of the fact that the required lifting force can only be produced by a more or less rapid translatory movement of the planes or foils. In actual experience the minimum speed for ascension and landing is a considerable fraction of that in full flight, and the principles of design do not admit of a very great advance in this respect without sacrifice of some desirable feature.

More recently professional attention has been turned to the helicopter, which is devoid of planes as distinct organs of support, and, presumably, enables both vertical and horizontal propulsion to be satisfactorily accomplished through the instrumentality of the propeller alone. However, although the idea is quite old and not a few experts have endeavored to carry it out in various ways, no practical success has yet been achieved.

A very serious defect of this kind of flying machine, from the practical point of view, is found in its inability of supporting itself in the air in case of failure of the motor, the projected area of the propeller blades being inadequate for reducing the speed of the fall sufficiently to avoid disaster, and this is an almost fatal impediment to its commercial use.

The type of machine to which this invention relates enables many of these disadvantages to be avoided but in order to obtain practical success I have found that provision must be made for the very different burdens which investigation shows fall upon the engine when the machine is being raised vertically and when it is being propelled horizontally and that to accomplish this an engine must be employed which is capable of standing a considerable over-load during the period of vertical ascent and of rotating at greatly increased speed during this time compared with the speed to be normally used during horizontal flight.

One of the features of this invention is the construction of an aeroplane of the above-named type actuated by an engine adapted to run at such over-load and for this purpose I use a prime-mover of the kind described in my British Patent No. 24,001 of 1910.

Another feature is that the machine is so constructed that it can start or descend either vertically as an helicopter or at an angle as an aeroplane and for this purpose two landing bases approximately at right angles to one another are provided.

Other subsidiary features of the invention are set out in the description following.

Full knowledge of these improvements will be readily gained by reference to the accompanying drawings in which Fig. 1 illustrates the machine in the starting or landing position and Fig. 2, in horizontal flight. Fig. 3 is a plan view of the same with the upper plane partly broken away.

The structure is composed of two planes or foils 1, 1, rigidly joined, the chord and gap of which may be nearly equal. The tail is omitted or, if used, it should be retractable. The motors 2, 2, in this case turbines of the kind described in my patent before referred to, and other parts of the motive apparatus are placed with due regard to the centres of gravity and pressure and the usual controlling means are provided. In addition to these any of the known stabilizing devices may be embodied in the machine. At rest the planes are vertical, or nearly so, and likewise the shaft driving the propeller 3, which is constructed of a strength, size and pitch that will enable it to raise the entire weight with the motor running at an even greater rate than when propelling the machine horizontally. Power is transmitted to the shaft from the turbines through suitable gears. The seats 4, 4, 4, for the operator and passengers are suspended on trunnions 5, 5 on which they may turn through an angle of about 90°, springs and cushions (not shown) being employed to insure and limit their motion through this angle. The usual devices for lateral and directional control, 6, 6, 7, 7 and 8, 8 are provided with mechanical connections enabling the operator to actuate the devices by hand or foot from his seat in any position. At the start, sufficient power being turned on by suitable means, also within his reach, the machine rises vertically in the air to the desired height when it is gradually tilted by manipulating the elevator devices and proceeds like on aeroplane, the load being transferred from the propeller to the foils as the angle of inclination diminishes and the speed in horizontal direction increases. In descending the forward speed may be reduced and the machine righted again, acting as a helicopter with the propeller supporting all the load. The type of turbine which, as stated above, I prefer is a motor of great lightness and activity and lends itself exceptionally to this kind of work for which ordinary aviation motors are unsuited. It is capable of carrying a great overload and running without danger at excessive speed so that during the starting and landing operations the necessary power can be developed by the motors even though less efficiently than under their normal working conditions. Special means of control may be provided, if necessary, for increasing the power supply in these operations. Owing to its extreme simplicity the motive apparatus is very reliable in operation. Ascent and descent can be effected either with the planes vertical or in the manner of aeroplanes of the usual type. For this purpose, in addition to wheels 9, 9 and 10, 10, wheels 11, 11 are employed, the latter being mounted on the forward end under the lower plane so that when the machine rests on level ground the propeller shaft will have the desired inclination which is deemed best for rising in the manner of an aeroplane. Such a helicopter-plane constructed and operated as described, unites the advantages of both types and seems to meet best the requirements of a small, compact, exceedingly speedy and yet very safe machine for commercial use.

Having now particularly described and ascertained the nature of my said invention, and in what manner the same is to be performed, I declare that what I claim is:—

1. A flying machine capable of vertical movement under the influence of its propeller or propellers and also of movement in the manner of an aeroplane actuated by a motor or motors so constructed that it or they are adapted to rotate its propeller or propellers at a speed greatly exceeding normal when rising or descending vertically while such speed can be reduced to the normal when it is flying horizontally and supported by its planes.

2. Flying machine as described and claimed in Claim 1 of which the motor or motors are of the type described in British Specification No. 24,001 of 1910.

3. Flying machine as described and claimed in the preceding claims actuated by a single propeller which when it is ascending vertically is above the centre of gravity of the machine.

4. A flying machine so constructed that it can start and descend either straight up and down like a helicopter or at an angle like an aeroplane and can be tilted as a whole in the air from its

vertical to its horizontal position and *vice versa*, substantially as described.

5. Flying machine as described and claimed in Claim 4 provided with two wheel bases substantially at right angles.

6. Flying machine as described and claimed in the preceding claim in which one or more wheels are common to the two bases.

7. Flying machine constructed substantially as described and shown in the drawings.

Dated this 25th day of August, 1922.

NIKOLA TESLA,
By James R. Hatmaker,
His Attorney.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1922.

[This Drawing is a reproduction of the Original on a reduced scale]

Fig. 1

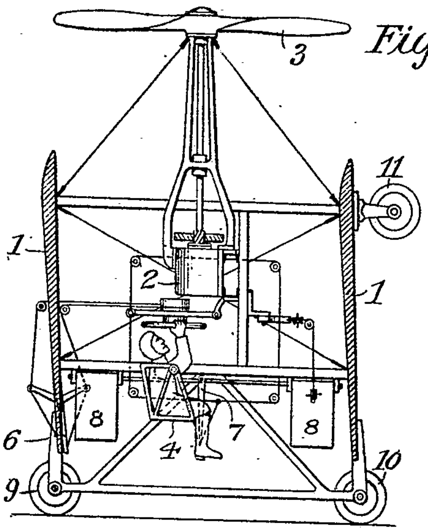


Fig. 2

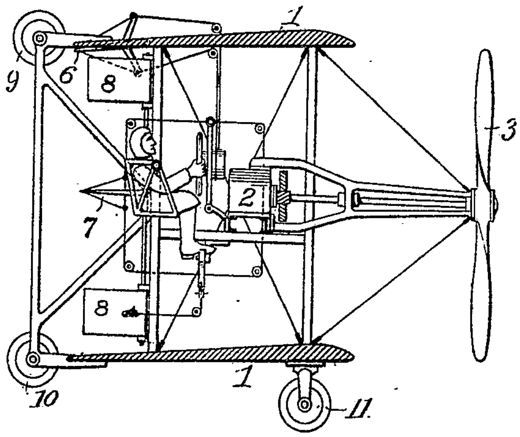
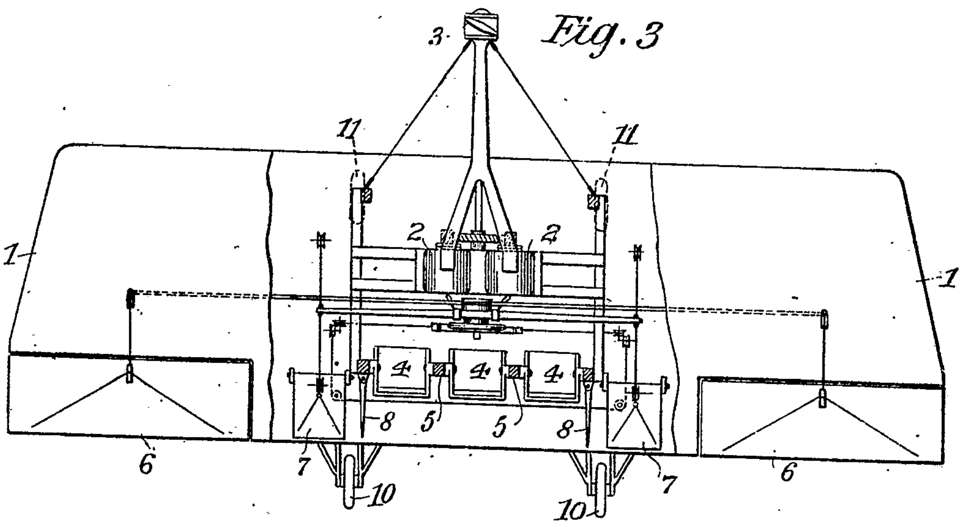


Fig. 3



PATENT SPECIFICATION

Application Date: Mar. 24, 1921. No. 9097/21.

186,082

Complete Left: Sept. 2, 1921.

Complete Accepted: Sept. 25, 1922.

PROVISIONAL SPECIFICATION.

Improvements in the Construction of Steam and Gas Turbines.

I, NIKOLA TESLA, Mechanical and Electrical Engineer, citizen of the United States of America, of 8, West 40th Street, New York City, U.S.A., do hereby declare the nature of this invention to be as follows:—

In a British Patent, Number 24,001 of 1910, I have described a bladeless turbine having a rotor consisting of discs with openings in the central portions and separating star-washers, these parts when assembled being riveted together into a single solid structure and keyed to the shaft. This form of rotor operates satisfactorily but in long experience certain improvements in its construction have been found desirable and these constitute my present invention.

In the new design I employ two heavier end-plates which are machined tapering toward the periphery for the purpose of reducing the maximum centrifugal stress as much as practicable. The inside discs, of relatively thin material, are rolled, forged or ground tapering in like manner and with the same object in view, but this may not always be necessary and plates, made of sheet metal of substantially uniform thickness as furnished by the mills, can be employed. Each of the thick as well as thin plates is provided with exhaust openings, leaving a solid central portion like the hub and spokes of a wheel. Star-washers of similar configuration serve the purpose of keeping the discs apart in the center and for the peripheral spacing the thin plates have small holes drilled in them on a circle, or circles, of suitable diameter, and in these are driven tight-fitting studs which are upset at both ends by a special tool so that they will project beyond the metal on each side a trifle more than the thickness of the star-washers. When the plates are put together the separating studs do not come in line but are straddled in order to give opportunity for slight yielding, thereby eliminating constructional difficulties which might be caused by unevenness or other mechanical imperfections. Thus the rotor can be finished closely to predetermined overall dimensions and will run true on the outside even if the thin inside plates should vary a little in thickness or be slightly warped. To simplify this arrangement I provide only every second plate with studs, using plain ones between. Furthermore, with the object of cheapening the manufacture I dispense altogether with the former, accomplishing the spacing by means of small bosses or protuberances which are raised in the plates by blows or pressure and provide a die, practically reducing all the machine work on a thin plate to a single operation in a stamping press. The star-washers, while preferable, are not indispensable and may be replaced by round separating washers of a diameter about equal to that of the hub part of the discs.

All the plates and washers are fitted on and keyed to a sleeve threaded at the ends and equipped with nuts and collars for drawing the thick end-plates together or, if desired, the collars may be simply forced onto it and the ends upset. The sleeve has a hole fitting snugly on the shaft and is fastened to the same as usual.

This construction permits free expansion and contraction of each plate individually under the varying influence of heat and centrifugal force and posesses a number of other advantages which are of considerable practical moment. A larger active plate area and consequently more power is obtained for a given width, this improving efficiency. Warping is virtually eliminated and smaller side clearances may be used which results in diminished leakage and friction losses.

The rotor is better adapted for dynamic balancing and through rubbing friction resists disturbing influences thereby insuring quieter running. For this reason and also because the discs are not rigidly joined it is safer against damage which might otherwise be caused by vibration or excessive speed.

Dated this 24th day of March, 1921.

NIKOLA TESLA.

COMPLETE SPECIFICATION.

Improvements in the Construction of Steam and Gas Turbines.

I, NIKOLA TESLA, Electrical and Mechanical Engineer, citizen of the United States of America, of No. 8, West 40th Street, New York, N.Y., U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In a British Patent, No. 24,001 of 1910, I have described a bladeless turbine having a rotor consisting of discs with openings in the central portions, and separating star-washers, these parts when assembled being riveted together into a single solid structure and keyed to the shaft. This form of rotor operates satisfactorily but in long experience certain improvements in its construction have been found desirable and these constitute my present invention.

In the new design, illustrated in the accompanying drawings Fig. 1 and Fig. 2, respectively showing a section through the rotor on line II and a side view partly broken away exposing a portion of a star-washer, I preferably employ two heavier end-plates 1, 1 of suitable material made tapering on the outside toward the periphery, as shown, for the purpose of reducing the maximum centrifugal stress as much as practicable. The inside discs 2, 2 . . . . are relatively thin and may be tapered on both sides in the peripheral part beyond the star-washers with the same object in view, but plates of substantially uniform thickness, as furnished by the mills, can also be employed. Each of the plates—thick as well as thin—is provided with exhaust openings 3, 3 . . . . leaving a solid central portion 4, 4 . . . . like the hub and spokes of a wheel. If there is an odd number of thin plates the central one may be plain, if desired. Star-washers 5, 5 . . . . of similar configuration, and projecting with their arms considerably beyond the exhaust openings, serve the purpose of keeping the discs apart in the central region and for the peripheral spacing the thin plates have small holes drilled in them preferably on a circle, or circles, of suitable diameter, and in these are driven tight-fitting spacers or studs 6, 6 . . . . which may be upset at the ends so that they will project on each side a trifle more than the thickness of the star-washers 5, 5 . . . . When the plates are put together the separating studs do not come in line but are straddled, as indicated in Fig. 1 and in the broken away part of Fig. 2 by the plain and dotted small circles, in order to give opportunity for slight yielding, thereby eliminating constructional difficulties which might be caused by unevenness or other mechanical imperfections. Such a rotor can be finished closely to predetermined overall dimensions and will run true on the outside even if the thin inside plates should vary a little in thickness or be slightly warped. To simplify the construction I provide only every second plate with studs, using plain ones between. Furthermore, with the object of cheapening the manufacture, I may dispense with the studs altogether, accomplishing the peripheral spacing by means of other spacers such as small bosses or protuberances raised in the plates, thus reducing the machine work on the thin ones to a single operation in a stamping press. The star-washers, while preferable, are not indispensable and may be replaced by round separating washers of a diameter about equal to that of the hub part of the discs.

All the plates and washers are fitted on and keyed to a sleeve 7, threaded at the ends and equipped with nuts 8, 8 for drawing the thick end-plates together or, if desired, the nuts and threads on the sleeve may be omitted, collars forced on its ends and the same upset. The sleeve fits snugly on the shaft 9 and is fastened to it as usual.

This construction enables the use of thinner inside plates then practicable in the earlier form, thus affording a greater active surface and increasing correspondingly the output, while the smaller clearances are instrumental in reducing the leakage losses.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. A rotor for steam and gas turbines

composed of plane spaced discs and two rigid end-plates holding them in fixed position laterally but permitting their independent expansion or contraction in the radial direction, said discs and plates being provided with exhaust openings in their central portions, substantially as described.

2. A turbine rotor comprising plane discs with spacers allowing radial displacement, central separating washers and two rigid tapering end-plates for holding the structure firmly near the shaft, said discs and end-plates having exhaust openings in their central portions, substantially as described.

3. In a rotor for high-speed turbines plane spaced discs with exhaust openings in their central portions and tapering towards the periphery as, and for the purpose, described.

4. A turbine rotor consisting of a system of discs held apart by spacers in frictional contact with them and alternately straddled as, and for the purpose, described.

5. A turbine rotor composed of plane parallel discs having exhaust openings in their central portions and projections for holding them apart near the periphery, substantially as described.

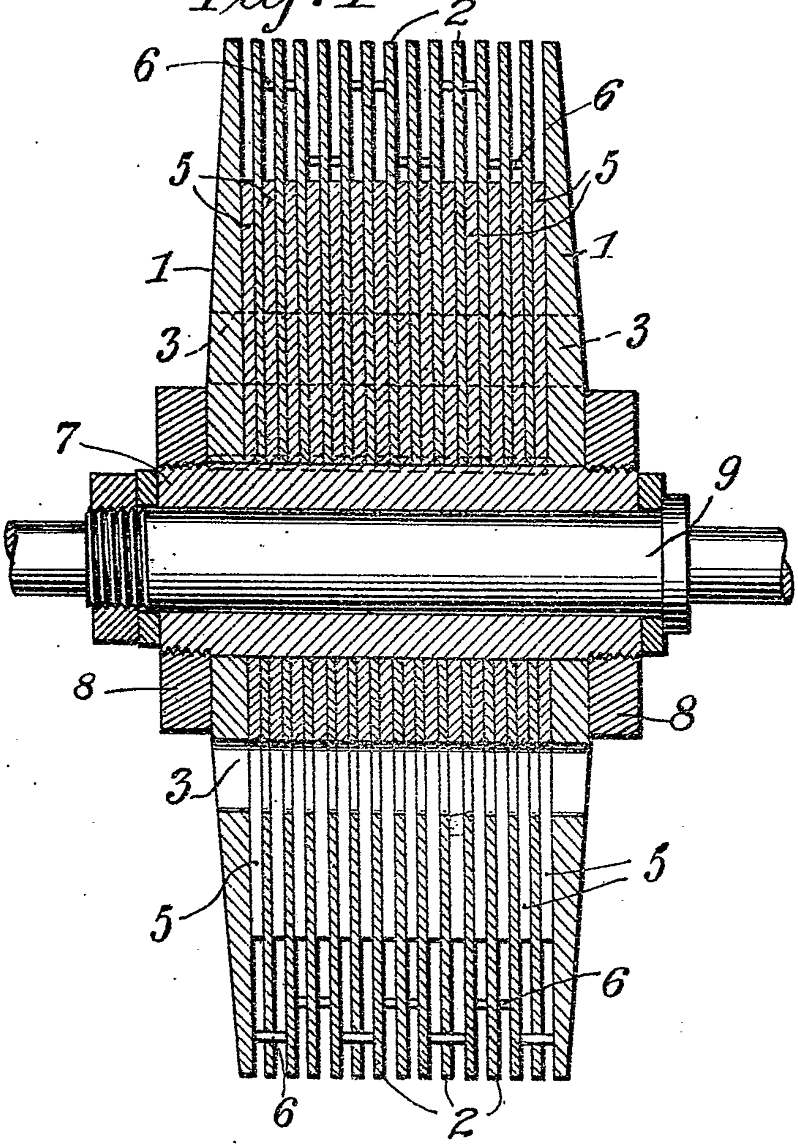
6. In a turbine rotor composed of flat discs with exhaust openings in their central portions, star washers of similar configuration and projecting with their arms considerably beyond the openings in the discs, substantially as described.

Dated the 23rd day of August, 1921.

NIKOLA TESLA.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1922.

Fig. 1



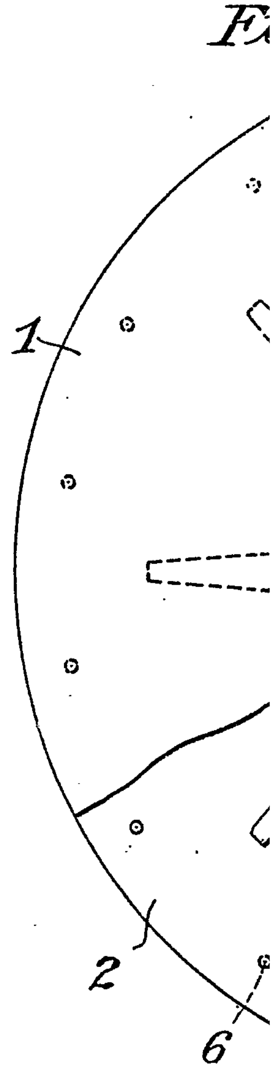


Fig. 2

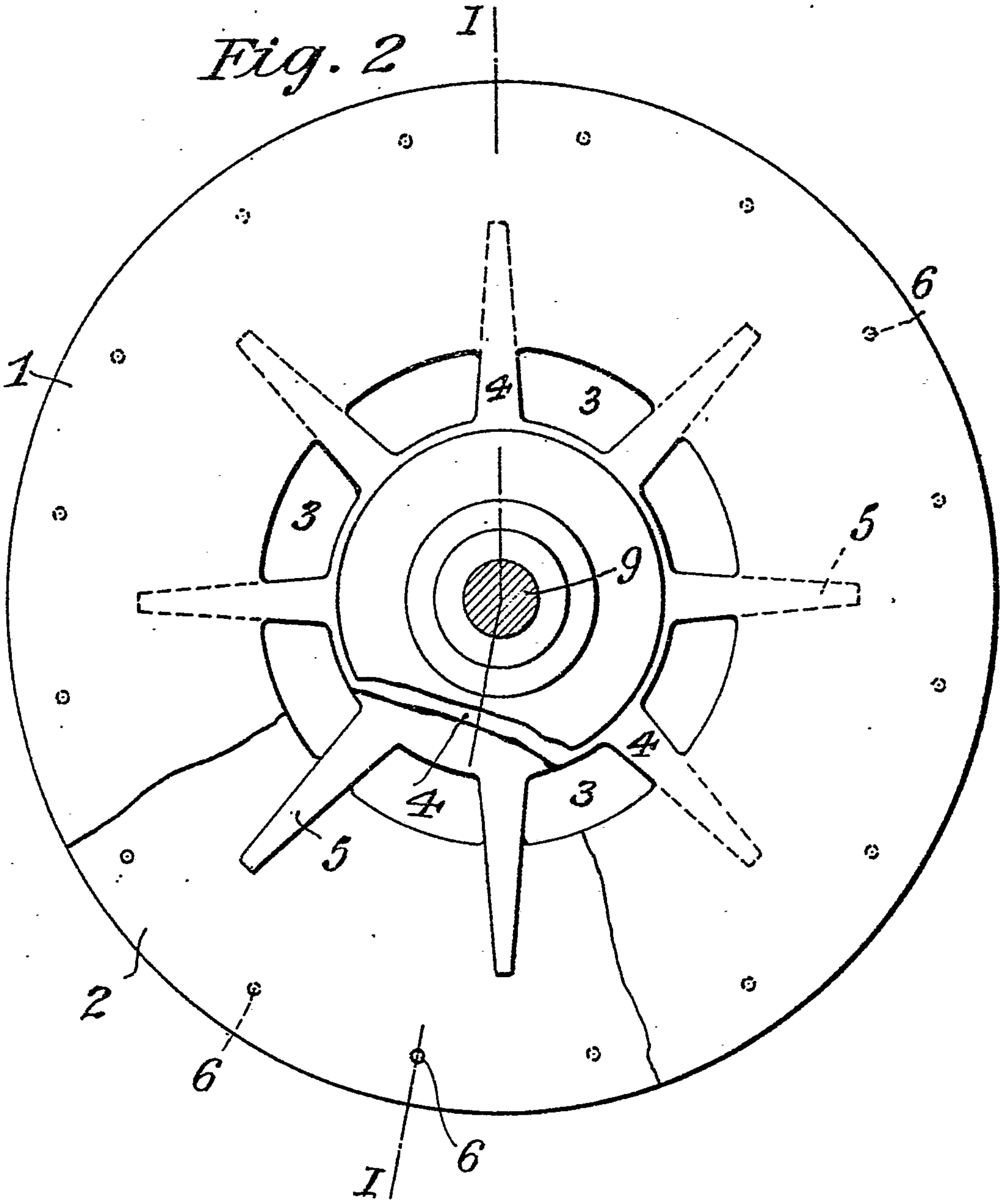


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Fig. 1

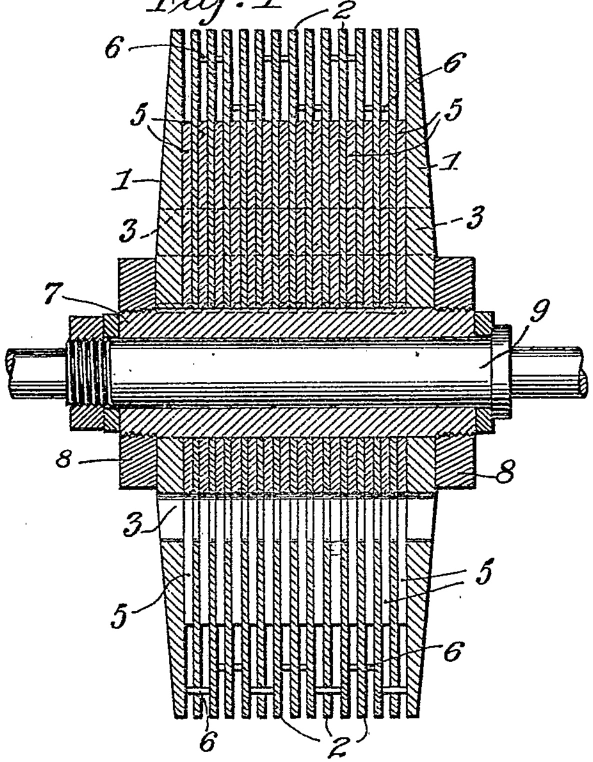
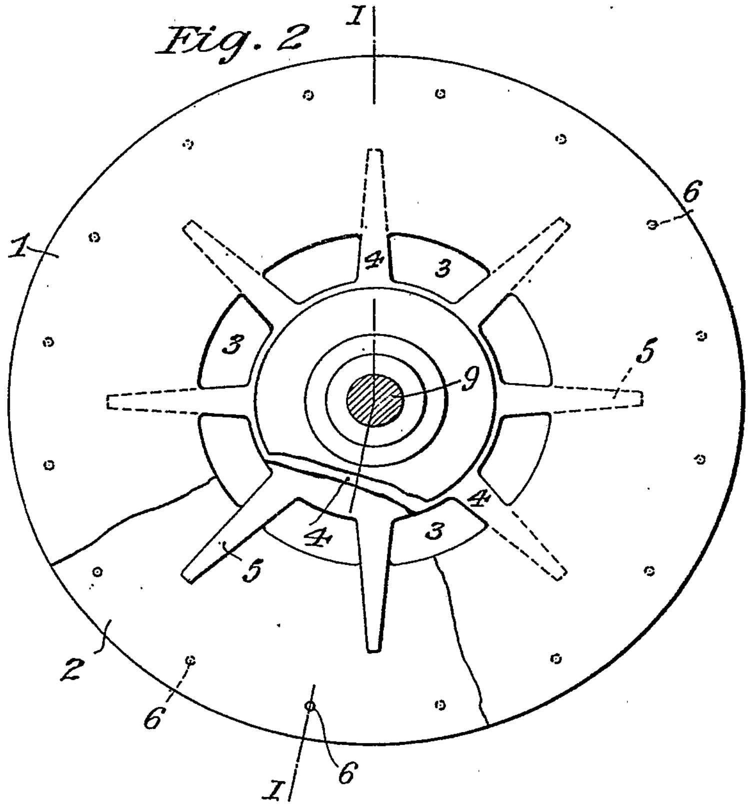


Fig. 2



[This Drawing is a full-size reproduction of the Original.]

Malby & Sons, Photo-Litho

PATENT SPECIFICATION

Application Date: Mar. 24, 1921. No. 9099/21.

186,083

Complete Left: Sept. 5, 1921.

Complete Accepted: Sept. 25, 1922.

PROVISIONAL SPECIFICATION.

Improved Method of and Apparatus for the Economic Transformation of the Energy of Steam by Turbines.

I, NIKOLA TESLA, Mechanical and Electrical Engineer, citizen of the United States of America, of 8, West 40 Street, New York City, U.S.A., do hereby declare the nature of this invention to be as follows:—

The chief object of my improvements is to increase the efficiency of the existing steam power plants and thermo-dynamic transformers operated therefrom, but they may also be applied with like effect apart from the present establishments and are intended for the broad purpose of producing motive power, more economically, through the medium of steam.

It is well-known that notwithstanding the multiplication of hydro-electric and gas engine installations, steam is still the main source of power, but as a rule only a low fuel efficiency is secured owing to limitations inherent to the thermal process itself, as now carried out, and certain shortcomings of the present forms of apparatus. Furthermore, plans which have been heretofore contemplated for the attainment of better economy generally involved technical obstacles, more or less radical changes and necessarily considerable expense. For instance, in order to minimize the heat losses incident to the raising of steam, it has been suggested to burn the fuel together with air in the boiler and operate the engines by the mixture of steam and gas thus obtained. So far, however, attempts to effect combustion satisfactorily under such conditions have not been very successful. High pressures hape been proposed with the same end in view but no great progress has yet been made in that direction; in fact many engineers view such projects with disfavor as they present a number of objectionable features and the possibilities of improvement are circumscribed. Again the employment of superheat as a means of increasing fuel efficiency is practicable only in a measure because the adopted types of prime movers do not lend themselves to high temperatures which, in conformity with the fundamental laws of thermodynamics, are indispensable to such a full realization.

These drawbacks have been successfully overcome in the method I have devised, which is very economical, readily applicable to the plants now in operation without appreciable modifications in them, and is rendered particularly advantageous through the instrumentality of a turbine or rotary engine described in my British Patent No. 24,001 of 1910 and improvements I have made in its construction since that time. This machine is capable of operating satisfactorily at very high temperatures, with cheap fuel, containing a large percentage of impurities, and without substantial impairment of efficiency as might be due to oxidation, roughening of the metal surfaces, or similar deteriorating actions which seriously interfere with the working of other heat engines now in use.

In applying my invention to a steam power plant I use air, under a pressure about equal to that of the boiler, for burning gas, crude oil, colloidal fuel or powdered coal in a chamber or conduit into which the steam is simultaneously admitted as cooling agent and diluent. The provisions to this end will greatly vary according to conditions. In central stations, factories, on shipboard and in many other places compressed air, as well as steam, is available and often, too, all the facilities for fuel storage and supply may be on hand. In such cases the benefits of my improvements will be readily derived with but little additional apparatus and at small cost. If the circumstances require, I provide an air- and also a gas compressor when necessary, driven directly from the shaft of the prime-mover or operated independently by electricity, steam or other motive agent. Generally these machines will be of the more efficient reciprocating type, but rotary compressors or both may be employed to secure some advantage. Irrespective of specific arrangements I effect the combustion while the fluids are in rapid motion and in a conduit preferably in close proximity to the engine, thus disposing of most of the difficulties previously encountered and at the same time materially reducing the radiation and conduction losses which would be incurred in the passage through long pipes. To better insure the maintenance of standard working conditions I may add to the equipment an equalizer of pressures operated differentially by the air and steam, but this device is not essential. The quantity of steam is so regulated that the highly heated mixture, upon expansion through the nozzle, attains an arbitrary temperature which the turbine can safely withstand. The elastic fluids, after traversing the rotor and giving up to the same a part of their kinetic energy, escape through the exhaust openings and serve the further purpose of preheating the feedwater, fuel, and likewise the air when desired. If intensely heated, the air and fuel will be conveyed to the combustion chamber separately, but in small installations it may be convenient to feed the fuel into the compressor or air pipe leading the carburated medium to the chamber. When simplicity is paramount, cheap coils or heaters for the combustibles and the feedwater will be resorted to, but in order to attain a still higher thermal efficiency I employ, besides, a small auxiliary boiler through which the exhaust is circulated. The steam thus obtained from waste heat is fed through a suitable valve, opening at the proper pressure, into the combustion space whence it passes, together with that furnished by the plant, through the turbine first doing useful work and then adding to the waste heat to be utilized in the manner set forth. More fuel may now be gradually admitted to maintain the normal temperature, this again increasing the heat in the exhaust and causing a more rapid generation of the steam, and so on, until finally a steady regime is established. However, if deemed of advantage under given operative conditions, the steam from the main boiler may be reduced in quantity in approximately the same measure as that from the auxiliary boiler is supplied.

This plan provides an efficient self-starting prime mover which may be operated as a steam- or mixed fluid turbine at will, without constructional change and is on this account very convenient. Minor departures from it, as may be dictated by the circumstances in each case, will obviously suggest themselves but if it is carried out on these general lines it will be found highly profitable to the owners of the steam plant while permitting the use of their old installation. However, the best economic results in the development of power from steam by my invention will be obtained in plants especially adapted for the purpose. It should be added that this method can also be successfully applied to condensing plants operating with high vacuum. In such a case, owing to the very great expansion ratio, the exhaust mixture will be at a relatively low temperature and suitable for admission to the condenser. Better fuel has to be used and special pumping facilities provided but the economic results attained will fully justify the increased outlay.

Dated this 24th day of March, 1921.

NIKOLA TESLA.

COMPLETE SPECIFICATION.

Improved Method of and Apparatus for the Economic Transformation of the Energy of Steam by Turbines.

I, Nikola Tesla, Electrical and Mechanical Engineer, citizen of the United States of America, of No. 8, West 40th Street, New York, N.Y., U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

The chief object of my improvements

is to increase the efficiency of existing steam power plants and thermodynamic transformers operated therefrom, but they may also be applied with like effect apart from the present establishments and are intended for the broad purpose of producing motive power, more economically, through the medium of steam mixed with the heated products of combustion, while the apparatus is capable of actuation by steam alone. It is well-known that notwithstanding the multiplication of hydro-electric and gas engine installations, most of the motive power is still derived from this agent, but only a relatively low fue efficiency is secured owing to limitations inherent to the thermal process itself, as now carried out, and certain shortcomings of the present forms of apparatus. These drawbacks have been largely overcome in the method I have devised, which is very economical, readily applicable to the plants now in operation without substantial modifications in them, and is rendered particularly advantageous through the instrumentality of a turbine or rotary engine described in my British Patent No. 24,001 of 1910 and improvements I have made in its construction since that time. This machine is capable of operating satisfactorily at very high temperatures, with cheap fuel containing a large percentage of impurities, and without material impairment of efficiency as might be due to oxidation, roughening of the metal surfaces or similar deteriorating actions which seriously interfere with the working of other heat engines.

In applying my invention to a steam power plant I use air, under a pressure about equal to that of the boiler, for burning gas, crude oil, colloidal fuel or powdered coal in a chamber or conduit, the products of combustion escaping from the same mixing with the steam on their way to the turbine being thus diluted and cooled to the desired temperature. The provisions to this end will greatly vary according to conditions. In central stations, factories, on shipboard and in many other places compressed air, as well as steam, is available and often, too, all the facilities for fuel storage and supply may be on hand. In such cases the benefits of my improvements will be readily derived with but little additional apparatus and at small cost. If the circumstances require, I provide an air- and sometimes also a gas-compressor driven either directly from the shaft of the primemover or independently by electricity, steam or other motive agent. Generally these machines will be of the more efficient reciprocating kind, but rotary compressors or composite types may be employed to secure some advantage. Irrespective of specific arrangements, I effect the combustion and mixing while the fluids are in rapid motion in a conduit which is, preferably, in close proximity to the turbine, thus disposing of most of the abovementioned difficulties previously encountered and at the same time considerably reducing the radiation and conduction losses which would be incurred in the passage through long pipes. To better insure the maintenance of standard working conditions, I may add to the equipment a device of the usual construction for equalizing the steam and air pressures. The quantity of steam is so regulated that the highly heated mixture, upon expansion through the nozzle, enters the turbine at a temperature which the machine can safely withstand. The elastic fluids, after traversing the rotor and giving up to the same a part of their kinetic energy, escape through the exhaust openings and may serve the further purpose of preheating the feedwater, fuel, and likewise the air when desired. If intensely preheated, the air and fuel will be conveyed to the combustion chamber or conduit separately, but in small installations it may be convenient to feed the fuel into the compressor or the air pipe thus bringing about a thorough mixture of the combustibles. When simplicity is of paramount importance, heaters may be resorted to for improving the economy, but in order to attain a still higher thermal efficiency I provide a boiler through which the working fluids, exhausted from the turbine, are circulated. The steam thus obtained from waste heat is fed through a suitable valve, into an inlet pipe whence it passes either separately or together with the mixed working fluid through the nozzle, first doing useful work and then adding to the waste heat of the exhaust. More fuel may now be gradually admitted to maintain in the inlet pipe the normal temperature, thus again increasing the heat in the exhaust and causing a more rapid generation of the steam, and so on, until finally a steady regime is established. However, if deemed of advantage under given operative conditions, the steam furnished by the plant may be reduced in quantity in approximately the same measure as that from the boiler is supplied.

My invention will be more fully understood by reference to the accompanying drawings in which Figure 1 illustrates the general arrangement of the apparatus comprising the turbine, a compressor, a storage tank for the fuel, a boiler and the necessary pipe connections and controlling devices, and Figure 2 a vertical cross-section of the main valve for admission of the steam and regulation of its flow.

In the first named figure, 1 represents my turbine with its shaft flexibly coupled to a machine performing useful work, as dynamo 2. The general construction of the turbine is preferably as described in my British Patent No. 24,001 of 1910, two nozzles being provided, which are intended to operate in the same direction. The nozzles are contained in two diametrically opposite enlargements of the casing and communicate with inlet pipes 3 and 4 which are joined, through suitable valves 5 and 6, to the main steam admission and control valve 7, shown in section Figure 2 and to be described in detail.

The air compressor can be of any kind but is shown of the reciprocating high speed type, driven by an electric motor 8, and comprising two stages 9 and 10, with an intercooler 11. A pipe 12 carrying valve 13, connects the discharge duct of the compressor to flanged conduits 14 and 15 which are bolted to the inlet pipes 3 and 4 as indicated and equipped with means for ignition, as spark plugs 16 and 17. An extension 18 of pipe 12 leads through a valve 19, to the top of the fuel tank 20 and serves the purpose of maintaining in the latter the required pressure. When the employment of an air reservoir is deemed preferable extension 18 will be put in communication with the same through valve 21. A filling pipe 22, armed with valve 23, is attached to the top of tank 20 while near to its bottom is joined a discharge pipe 24 provided with valve 25 leading through a needle valve 26 to an automatic control valve 27 which is connected by pipes 28 and 29 to the flanged conduits 14 and 15.

The main valve 7 is designed for control of the steam flow both by automatic means and independently of the same. Its construction is clearly indicated in Figure 2, representing a vertical cross-section. The device consists of a casting 30 with inlet ports 31 and outlets 32 and 33, which are joined by flanges to pipes 3 and 4. The open bottom of the casting is connected to a steam inlet pipe 34 while the top carries a throttle valve 35 for turning on and shutting off the steam. Below the seat of this valve the casting has a transversal bore, into which is freely fitted a hollow cylinder 36 with balanced intake and exhaust openings, the latter registering with outlets 32 and 33 in the casting. The cylinder 36 is rigidly joined through a rod 37 with a hollow plunger 38 (Fig. 1) having diametrically opposite ports matching those in the stationary part of valve 27.

The boiler 39, which may be of the vertical tubular type as illustrated, is connected through its headers 40 and 41 on the lower end to main 42 communicating with the exhaust opening 43 of the turbine, and on the upper one to discharge conduit 44 through which the hot fluids, after traversing the boiler tubes, escape into the atmosphere or are led to an economizer for preheating the feed-water or otherwise utilizing the waste heat. A conduit 45 joins the top of the boiler to inlet pipe 3 through a suitable valve 46 which may be operated either by hand or automatically.

From the foregoing the operation will now be readily understood. At the start valve 46 being closed and 5 and 6 open, steam from the plant is admitted through throttle and control valve 7 whence it passes into the inlet pipes 3 and 4 and communicating nozzles from which it issues at high velocity setting the rotor in motion, the machine operating purely as a steam turbine. The spark plugs 16 and 17 are then brought into play and valves 13, 19 and 25 opened, the latter allowing the fuel to flow from the tank, chiefly under the action of gravity, to needle valve 26 which is gradually turned on. The fuel thereupon passes through the ports of hollow plunger 38 and pipes 28 and 29 into apparatus for mixing and combustion, the construction of which is clearly shown in the cross-section at the lower branch, it being understood that the arrangement on the upper branch is identical. As will be seen the conduit 15 is armed on one end with a spraying device and on the other with a funnel-shaped extension which is held tight between flanges and projects far into the steam inlet pipe 4. The fuel, atomized by the inrushing air, enters the combustion chamber formed by an enlargement in conduit 15, and is then ignited in the same, the products of combustion escaping into the inlet pipe 4 and mixing with the steam on their way to the nozzle. This kind of apparatus overcomes the difficulty heretofore encountered in attempts to effect combustion practically and will work satisfactorily even if there are considerable fluctuations in the steam and air pressures, as the faster moving fluid aspirates the slower one. It has been assumed that liquid fuel is used but powdered coal may also be employed in substantially the same manner with slight constructive modifications, the powder being conveyed to the combustion chamber either independently of, or with, the air. The quantity of the combustibles is so regulated by manipulation of valves 13 and 26 (and also 5, 6 and throttle 7, if suitable) that the mixture, escaping from the nozles, will be at a temperature considered safe for the operation of the turbine. To facilitate this any of the well-known compound valves may be provided for the purpose of admitting the combustibles always in the required proportions irrespective of their total quantity.

When the steam in boiler 39, raised by the exhaust mixture passing through the tubes, attains the required pressure, it is admitted through valve 46, conduit 3 and corresponding nozzle, to the rotor, adding kinetic energy to the same. Feed-water, preferably heated by the turbine exhaust, is supplied to the boiler in the same measure as steam is drawn off, any ordinary means to this end being employed.

The automatic control of the flow of steam and fuel may be effected by any kind of speed governor operatively connected to rod 37 so that the supply is reduced as the speed increases. In addition to the means shown, an air valve may be provided, actuated automatically by the governor either through rod 37 or otherwise. For further convenience and to enable the independent control of the air and fuel supply in the two branches, conduits 14, 15 and pipes 28, 29 may be equipped with valves, indicated in Fig. 1, the numbering of which is deemed unnecessary.

The amount of power obtainable from boiler 39 will vary according to conditions. Turbines as described in my said prior specification are capable of operating at a very high exhaust temperature and then the energy recovered from the waste heat in this manner may be a large fraction of the whole useful work. In such as case conduit 3, pipes 14 and 28 together with all their adjuncts, as illustrated, can be omitted and the steam supplied directly to the nozzle through valve 46. Or these connections and adjuncts may be left undisturbed and a separate nozzle provided. In admitting the steam from the boiler to the turbine rotor through independent channels, the practical advantage is secured that the pressure may vary considerably without detracting much from the efficiency of the machine, which will be improved through preheating of the combustibles by any of the well-known means.

This plan provides an efficient self-starting mixed-fluid turbine which may also be operated with steam alone, merely by shutting off the air and fuel supply, and is on this account very convenient. Minor departures from it, as may be dictated by the circumstances, will obviously suggest themselves, but if it is carried out on these general lines it will be found highly profitable to the owners of the steam plant while permitting the use of their old installation. However, the best economic results in the development of power from steam by my invention will be obtained in plants especially adapted for the purpose. It should be added that this method can also be successfully applied to condensing plants operating with high vacuum. The production and maintenance of the latter will be materially facilitated by the employment of a pump as shown in my British patent before referred to. In such instances, owing to the very great expansion ratio, the exhaust mixture will be at a relatively low temperature and suitable for admission to the condenser. This will call for better fuel and special pumping facilities, but the economic results attained will fully justify the increased outlay.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. In a turbine installation normally working with a mixture of steam and products of combustion and in which the exhaust heat is used to provide steam which is supplied to the turbine, providing a valve governing the supply of such last mentioned steam so that the pressures and temperatures can be adjusted to the optimum conditions of working.

2. A turbine installation as described and claimed in Claim 1 so arranged that it is capable of starting with steam alone.

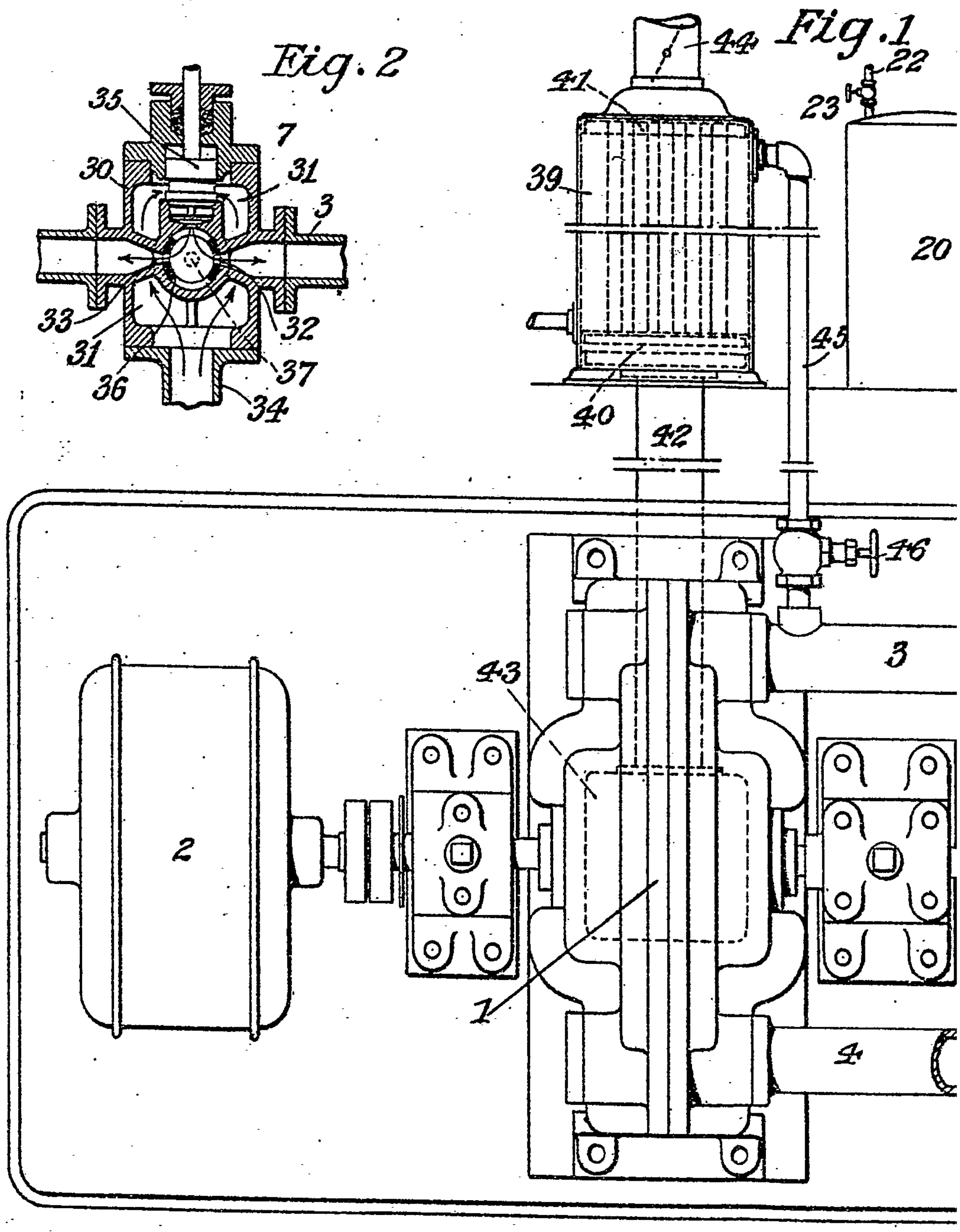
3. A turbine installation as described and claimed in Claim 1 or 2 in which the turbine is of the friction disc type adapted to work with fluids at a very high temperature such as is described in Specification 24,001 of 1910.

4. The combined apparatus substantially as described and shown in the drawings.

Dated the 23rd day of August, 1921.

NIKOLA TESLA.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1922.



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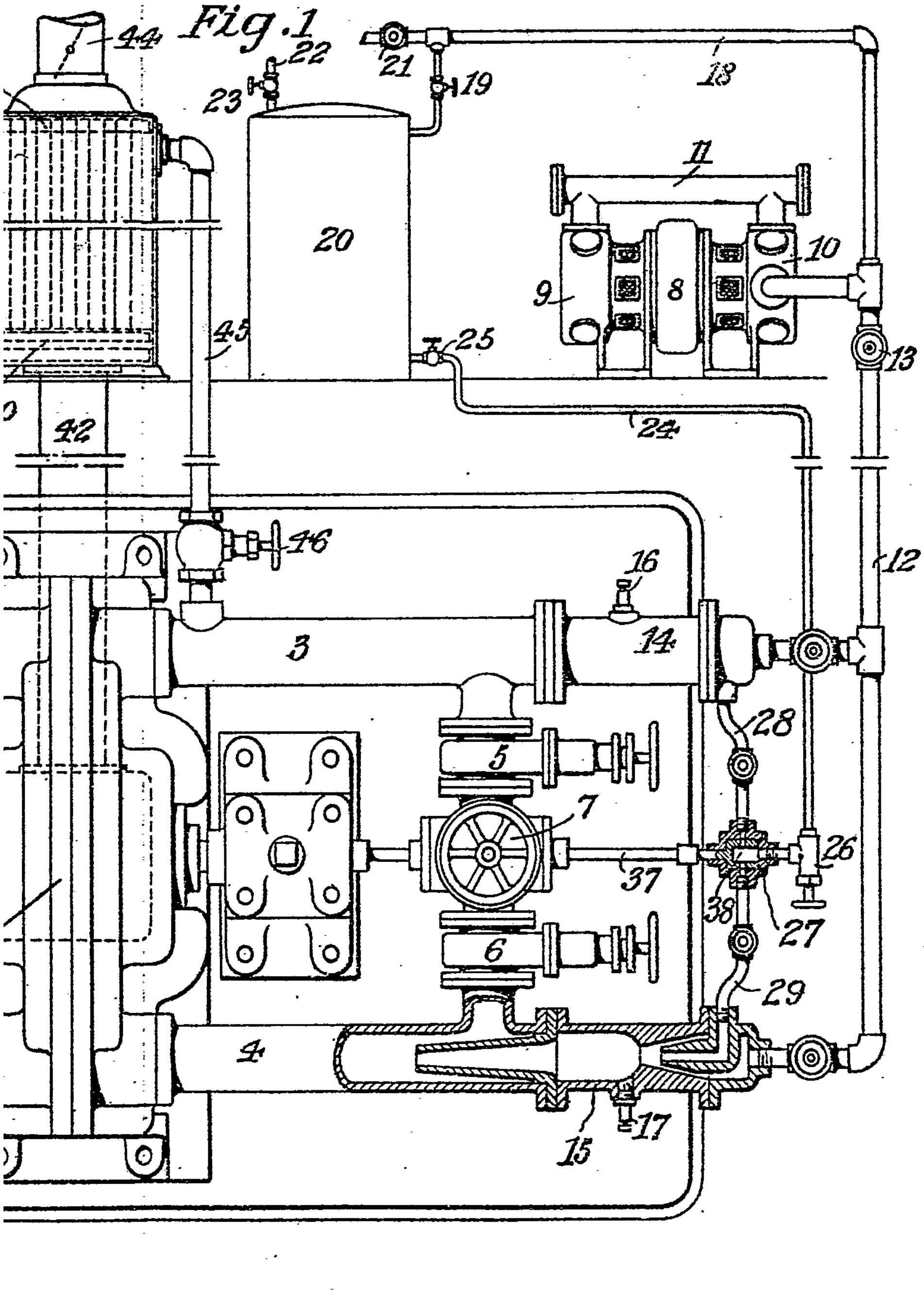
Fig.1
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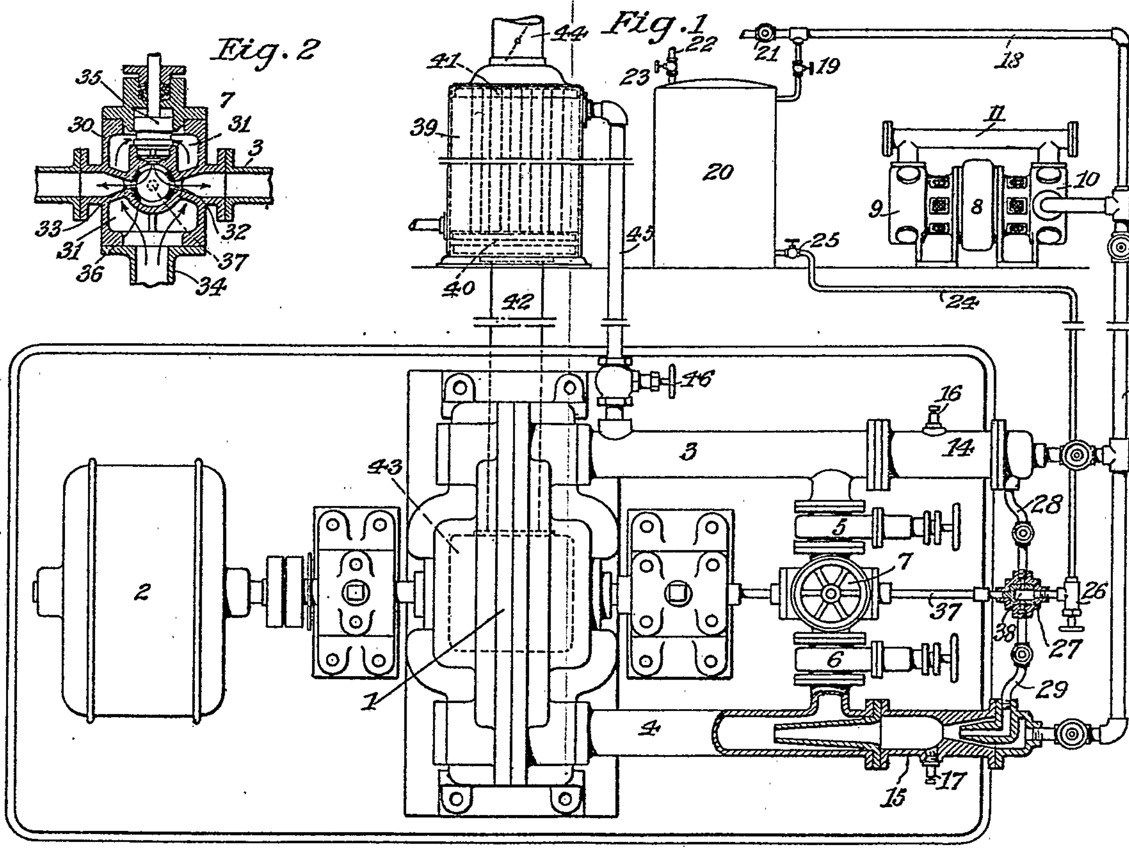
Fig. 2



[This Drawing is a full-size reproduction of the Original.]

PATENT SPECIFICATION

Application Date: Mar. 24, 1921. No. 9100/21.

186,084

Complete Left: Sept. 2, 1921.

Complete Accepted: Sept. 25, 1922.

PROVISIONAL SPECIFICATION.

Improved Process of and Apparatus for Deriving Motive Power from Steam.

I, NIKOLA TESLA, Mechanical and Electrical Engineer, Citizen of the United States of America, of 8, West 40 Street, New York City, U.S.A., do hereby declare the nature of this invention to be as follows:—

This improvement provides a very simple means for increasing the economy of steam turbines and is chiefly intended to be used in the operation of small units but may also be applied, with more or less success, to machines of considerable capacity, the saving effect depending largely on the conditions existing in the steamplants where it is introduced. The economic gain will be especially pronounced in factories and industrial establishments in which the steam pipes are long and serious loss is incurred through condensation and otherwise. The apparatus for carrying out the process is capable of slight modifications and can be employed in conjunction with different types of turbines, but is particularly suited to that described in my British Patent No. 24,001 of 1910, in which propulsion is effected by the adhesive and viscous action of the motive fluid. Irrespective of constructive features the general arrangement will be as follows:

The steam from the boiler is led through a superheater to the turbine nozzle and the high velocity jet projected from it against the rotor creates a suction in the adjacent space which is connected to the superheater pipes or coils, thus causing a strong air current to pass through the same. The air first enters a chamber to which gas or other fuel is supplied and the products of combustion are aspired through the coils into the turbine, superheating the steam to the desired degree, also increasing the temperature of the stream through the turbine rotor and, incidentally, imparting to it some of their kinetic energy. All of these actions co-operate in raising the efficiency of the machine with the result of bringing about an important reduction of operative expense.

To improve the performance of the apparatus I employ two concentric nozzles, steam being admitted to the turbine through one and the products of combustion through the other. Furthermore, in order to turn to good use the waste heat of the exhaust I attach to the latter an economiser for preheating the feedwater and fuel, thereby effecting additional saving.

This invention dispenses with the compressor ordinarily required in connection with a gas turbine and will be found valuable on account of its extreme simplicity, low cost of installment and facilities it affords.

Dated this 24th day of March, 1921.

NIKOLA TESLA.

COMPLETE SPECIFICATION.

Improved Process of and Apparatus for Deriving Motive Power from Steam.

I, NIKOLA TESLA, Electrical and Mechanical Engineer, citizen of the United States of America, of 8, West 40th Street, New York, N.Y., U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This improvement provides a very

simple means for increasing the economy of steam turbines and is chiefly intended to be used in the operation of small units but may also be applied, with more or less success, to machines of considerable capacity, the saving effect depending largely on the conditions existing in the steam-plants where it is introduced. The economic gain will be especially pronounced in factories and industrial establishments in which the steam pipes are long and serious loss is incurred through condensation and otherwise. The apparatus for carrying out the process is capable of slight modifications and can be employed in conjunction with different types of turbines, but is particularly suited to that described in my British Patent No. 24,001 of 1910, in which propulsion is effected by the adhesive and viscous action of the motive fluid. Irrespective of constructive features the operation will be generally as follows:

The steam from the boiler is led to the nozzle through a superheater, which should be placed as near as possible to the turbine, and the high velocity jet, projected from it against the rotor, creates a suction in the adjacent space which is connected to the superheater pipes or coils, thus causing a strong air current to pass through the same. The air first enters a combustion chamber to which gas or other fuel is supplied and the products are aspirated through the coils into the turbine, superheating the steam to the desired degree, also increasing the temperature of the stream through the turbine rotor and, incidentally, imparting to it some of their kinetic energy. All of these actions co-operate in raising the efficiency of the machine with the result of bringing about an important reduction of operative expense.

To improve the performance of the apparatus, I preferably employ two concentric non-convergent nozzles, steam being admitted to the turbine through one and the products of combustion through the other. Furthermore, in order to turn to good use the waste heat of the exhaust I may attach to the latter an economiser for preheating the feed-water and fuel, thereby effecting additional saving.

The preferred form of apparatus for carrying out the process above described is illustrated in the accompanying drawings in which Fig. 1 is a side view in elevation, partly cross-sectioned, and Fig. 2 a vertical section through one of the parts for supplying steam and combustion products to the turbine.

Referring to the figures more specifically, 1 is the rotor and 2, 2 the enclosing casing of the turbine which is provided with two diametrically opposite enlargements 3, 3 bored out and fitted with concentric conduits 4, 4 and 5, 5 for supplying the working fluids to the rotor. These are equipped with, or form part of, corresponding discharge nozzles 6, 6 and 7, 7. The superheater consists of a steam-chamber 8 closed at the ends by plates 9 and 10 and containing a coiled pipe 11, the ends of which are led out, one being connected to a combustion chamber 12 and the other to an outlet pipe 13 with branches 14 and 15 leading to the inner supply channels 16, 16. Steam inlet and outlet pipes, respectively, 17 and 18, are provided, the latter with two branches 19 and 20 communicating with channels 21, 21 of the supply part. Suitable steam, air and gas inlet valves, respectively marked 22, 23 and 24 may be employed for controlling and regulating the supply of the working fluids to the turbine. All the supply channels should be of a section sufficiently large so that the velocities of the fluids through them will be small as compared with those attained in the nozzles.

The operation will now be readily understood. Valves 23 and 24 being closed, the steam admitted by valve 22 passes through inlet pipe 17, chamber 8, outlet 18, branches 19 and 20, spaces 21, 21 and nozzles 6, 6, setting the turbine rotor in motion thus operating the machine as a simple steam turbine subject to the usual limitations in economic performance. The inlet valve 23 is now opened permitting the atmospheric air to be drawn in through coil 11, pipe 13, branches 14 and 15, channels 16, 16 and nozzles 7, 7 to the rotor. Power gas or other fuel is then admitted through valve 24 and upon being ignited in the combustion chamber 12 the products pass through in like manner, assisted by their initial velocity. As a result of this action, coiled pipe 11 is heated to a high temperature and superheats the steam in chamber 8 and also in the supply channels and nozzles, thus adding very materially to the available energy of the steam, at the same time increasing the efficiency of thermodynamic transformation. The products of combustion themselves, impinging against the rotor, contribute usefully some of their kinetic energy. The economic gain effected in this simple manner will be all the more pronounced the poorer the initial quality of the steam and the higher the pressure supply. However, low-pressure steam, as that exhausted from turbines or reciprocating engines, may likewise be economically utilized by this process and means, especially if provision is made for maintaining a vacuum at the exhaust end of the turbine.

The apparatus described is capable of minor modifications. For instance, the combustibles may be admitted to the rotor through the outer channels and steam through the inner ones. Again, the nozzles instead of being co-axial, as shown, may be otherwise constructed and disposed, or single nozzles may be used in their place and the mixture of the steam and gases effected before admission to them. However, this can be more or less completely accomplished with co-axial nozzles, as illustrated, merely by shortening one of them. As to the superheater it may be of widely varied design and incorporated with the turbine casing for the purpose of saving energy, weight and space. Departures may also be made in the design of the combustion chamber to suit the fuel employed and the necessary adjuncts for carburation and ignition will be provided, all of which, being well-known, are omitted from the drawing for the sake of clearness. Obviously, the process can be applied with more or less success in the transformation of the heat energy of elastic fluids other than steam.

This invention provides a self-starting, compact and efficient mixed-fluid turbine and will be found valuable on account of its extreme simplicity, low cost of instalment and the facilities it affords.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is:—

1. The hereinbefore described process of thermo-dynamic transformation of energy which consists in admitting steam to a turbine nozzle, aspirating by the suction thus created hot products of combustion through a heater, superheating the steam by them and discharging them at high velocity and in a direction parallel to the steam-jet upon the rotor, as described.

2. The process of increasing the efficiency of steam as motive agent which consists in admitting it through a heater to a turbine nozzle, aspirating by the suction thus created hot products of combustion through the heater thereby raising the temperature of the steam to a high degree and discharging the products at high velocity and in contact with the steam-jet upon the rotor, as described.

3. The method of operating a mixed fluid turbine which consists in starting it by steam admitted to the nozzle, aspirating by the suction produced in the space adjacent to the same hot products of combustion, superheating the steam by them and directing them upon the rotor so as to assist in driving it, as described.

4. The herein described process and apparatus by which a turbine rotor is started by steam and combustible fluids are aspirated by the suction of the steam-jet into a combustion chamber, the products of combustion serving to superheat the steam and then assist in driving the rotor.

5. In the process described and claimed in Claims 1, 2 and 3, the use of a friction turbine of very small windage.

6. In the process and apparatus described and claimed in Claim 4, the use of concentric non-convergent nozzles opening directly into the rotor chamber of the turbine.

7. In a mixed fluid turbine in which a secondary fluid is aspirated by the suction of the primary, the employment of non-convergent co-axial nozzles for discharging the fluids in parallel contacting streams upon the rotor, as described.

Dated the 23rd day of August, 1921.

NIKOLA TESLA.

Redhill: Printed for His Majesty's Stationery Office, by Love & Malcomson, Ltd.—1922.

Fig. 1

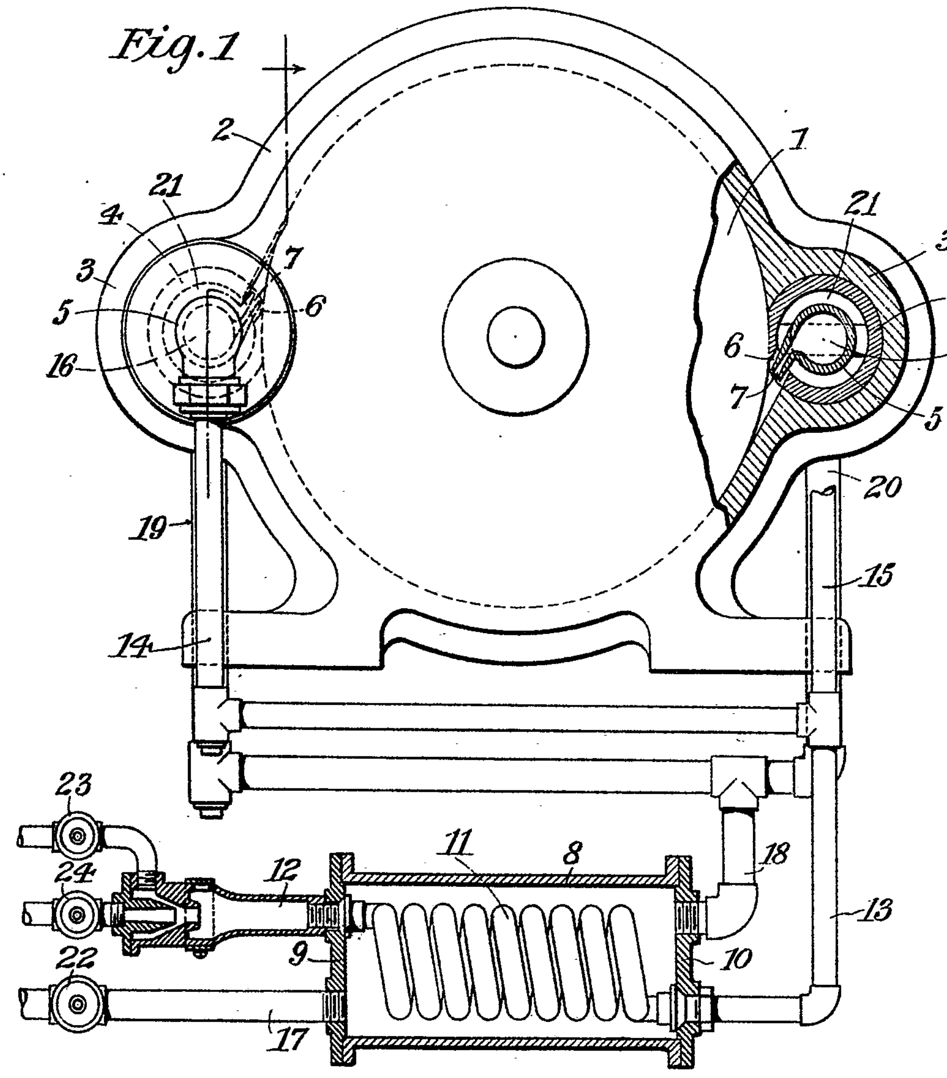
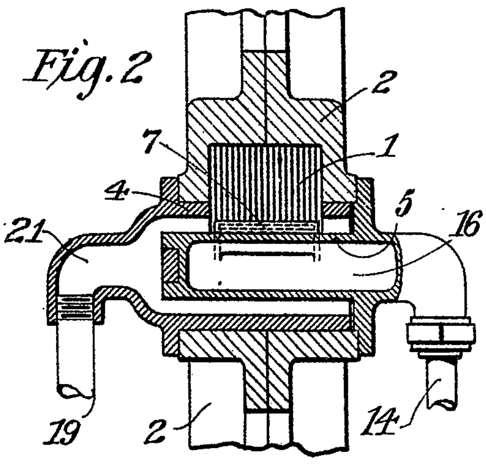


Fig. 2



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[Second Edition.]

PATENT SPECIFICATION

186,799

Application Date: Sept. 2, 1921. No. 23,336/21.

Complete Accepted: Oct. 12, 1922.

COMPLETE SPECIFICATION.

Process of and Apparatus for Balancing Rotating Machine Parts.

I, NIKOLA TESLA, Electrical and Mechanical Engineer, citizen of the United States of America, of No. 8, West 40th Street, New York, N.Y., U.S.A., do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In the operation of machinery the accurate balancing of the rotating parts is of great economic importance as vast sums of money are annually expended on account of deficiencies in this respect resulting in loss of power, undue wear and tear, interruption of service and accidents of a more or less serious nature.

Prior to the development of modern high speed apparatus static balancing was depended upon entirely and even now this is frequently the case. The steadily increasing tendency in the direction of high speed brought on the necessity of dynamic balancing and various forms of apparatus for this purpose were devised.

The process I have invented enables this to be done quickly and with a high degree of accuracy and, briefly stated, consists in rotating the body to be balanced, yieldably supported, at a suitable speed and removing excess material from its heavier side by abrasion, until the desired degree of perfection of balance is attained.

As means to this end I may employ a grinding wheel, a sand-blast or jet of other abrasive substance. It might be naturally inferred that the contact of an emery or carborundum wheel with a rapidly whirling machine part would be productive of dangerous shocks and vibrations, and also that grinding at speeds much higher than the usual could now be satisfactorily accomplished. But although these theoretical assumptions appear sound, I have encountered no difficulties of this kind and have performed the operation with the greatest facility and success. This I attribute to the inertia and momentum of the spinning body which makes it insensitive to such asynchronous disturbances as the wheel might produce. However, in certain cases it may be more convenient or preferable to effect the removal of the excess material by a high velocity jet of abrasive substance applied tangentially to the part to be balanced. In order to attain the best results it is essential that the latter, when rotated, shall be capable of an appreciable displacement of its center of gravity from the axis of symmetry. This is accomplished by supporting it on a shaft of suitable flexibility or, if its own shaft is not sufficiently flexible, in bearings yieldably mounted. It is furthermore of great importance, in order to avoid vibrations which would interfere with the proper application of the process, that the speed at which the grinding is effected should bear a definite relation to the critical, corresponding to the fundamental natural vibration, and the following rule should be observed: If the system is run in two bearings the grinding speed should be an odd multiple or submultiple of the critical. If, on the other hand, the system is supported on one side only, the speed should be an even multiple or submultiple of the critical.

When the structure is revolving at the proper speed I bring the abrasive wheel into operative contact with it at a peripheral or other suitable region and grind off material. As the action continues, the flexure of the shaft diminishes until, finally, its center of symmetry coincides with the center of gravity of the system, or nearly so. This can be noted in many cases by a competent operator without the use of a special device, but suitable visible or audible means may be employed for the purpose.

Preliminary to the application of the process it is advisable to run the part at a very low speed and true it with the wheel. If there exists appreciable flexure of the shaft when the system rests horizontally, the grinding may be done in a vertical position when it is in static balance. A part to be run on a stiff shaft may be mounted on another of suitable flexibility; and as there exist limitations in the accuracy of fitting a cylindrical sleeve, I may employ a tapering one to secure greater precision. However, satisfactory results can generally be obtained in arming the rigid shaft with flexible extensions or holding it in bearings yieldably supported. In all cases it is desirable to flood the latter with lubricant of considerable viscosity. When balancing parts to be run at a high temperature they may be inclosed in a casing in which approximately the same temperature is maintained, an opening being provided for the introduction of the abrasive wheel or jet.

My invention will be clearly understood by reference to the accompanying drawings illustrating a form of apparatus I have devised for the quick and convenient balancing of such bodies as rotors of my steam and gas turbines. Fig. 1 shows the general arrangement of the component parts comprising, a casing with an opening on one side, lathe mechanism for feeding the wheel, a tachometer enabling instantaneous readings of the speed to be taken, an instrument for continuous visual indication of the degree of accuracy obtained and a preheater of the elastic medium such as compressed air used in the operation; Fig. 2 represents a section through the casing in the plane of a rotor disc, exposing the said opening and also the turbine nozzle; Fig. 3 is a view of the essential parts of the balance-indicating instrument and, Fig. 4 illustrates the manner in which a jet of abrasive substance is applied when carrying out my process.

Calling attention specifically to the figure first named 1 is a casing, enclosing an air- or steam-driven rotor to be balanced, and shown as open at 2 for the purpose of permitting the wheel 3 to be brought into operative contact with the surfaces to be ground. Any suitable drive may be employed but I ordinarily resort to the electric, mounting the wheel directly on the shaft of a motor 4 fixed to a lathe carriage 5 which slides on rails 6, 6 and is provided with means 7 and 8 for feeding the wheel, respectively, along the axis of the motor shaft and at right angles to the same.

As shown in Fig. 2 the casing is split horizontally on the centerline in two castings 9 and 10, carefully planed so as to insure their coming into the same position whenever put together, lateral displacement being prevented by dowel-pins 11, 11 (Fig. 1) which are driven tight either in casting 9 or 10. These are enlarged and bored out on one side and into the hole is snugly fitted a hollow cylinder 13 with nozzle 14 and intake opening 15 directly connected to the supply pipe 16 provided with a suitable control valve. The opening at 2 for the entrance of wheel 3 is shown as a simple opening through the casing, but in certain cases I introduce the wheel through an enlargement of the casing similar to the enlargement shown in Fig. 2 on the right side, which is often convenient when balancing a rotor in its own casing.

Referring again to Fig. 1 the bearings 17 and 18 are also divided horizontally in the plane of the casing joint and their upper and lower parts may be integral with the corresponding castings 9 and 10 for the purpose of saving labor and time. The lower parts of the bearings are equipped with oil supply and discharge pipes 19 and 20. The supply pipe 16 is shown as connected to a coil 21 of a heater 22 which is equipped with a valve for controlling the flow of the heating medium and may be of any known construction. A worm drive 23 is provided on one end of the rotor shaft for operating the tachometer 24 through a flexible connection. This device may be of any make but I find it advantageous to use the air friction type. On the other end of the shaft is mounted the balance indicator 25 (shown in detail Fig. 3) consisting of a member 26 with a pointer 27 on the top and an adjustably mounted weight 28 on the bottom. This member is supported on the outer race 29 of a ball-bearing 30, the inner one 31 being fixed to the shaft, and is thus capable of oscillation, the rotary effort necessary to produce a given deflection of the same being determined by the position of the weight. A graduated scale 32 is attached to the stationary part of the instrument which is placed conveniently for observation by the operator.

Substantially the same apparatus, with the exception of wheel 3, may be employed in connection with the device diagrammatically illustrated in Fig. 4, in which a suitable fixture 32 projects a jet 33 of abrasive substance tangentially upon the body 34 to be balanced which is supported on a flexible shaft 35. In this case of course the fixture is mounted on carriage 5 to enable feeding in two directions.

The balancing is done as follows: The rotor being in position for grinding the casting 9 and covers of bearings 17 and

18 are put in place, lubricant forced through pipes 19 and 20 and a motive fluid as compressed air, admitted to nozzle 14, its quantity and temperature being regulated, respectively, by valves on supply pipe 16 and heater 22. The fluid, in traversing the rotor and exhausting through the lower casing imparts motion to the former and brings it up to the desired speed, ascertained by reading of tachometer 24. The abrasive wheel 3 is now fed across the rotor and the indication of the balancing instrument on the graduated scale noted. At the start the deflection of the pointer is likely to be considerable due to the fact that any, however slight vibration of the shaft, increases greatly the pressure on the balls and consequently the torque of the instrument. As the balance improves the deflection diminishes until finally the pointer reaches the zero of the scale indicating that the desired degree of perfection of balance has been attained. As a crucial test the operator may then run the rotor at about the critical speed. This should cause no appreciable vibration or effect on the balance indicator which, instead of carrying a weight, may be equipped with a spring for producing the required pressure on the ball-bearing and opposing the torsion.

When bodies not adapted for rotation in the manner shown are to be balanced, they will be driven independently by belt, electricity or other means, care being taken that no disturbing vibration from them is transmitted to the apparatus. In order to preserve intact the peripheral boundary, if this is essential, I grind the material off from some other place and when desirable, I make a special provision to this end in the design and construction of the part.

I have found my process very valuable in the balancing of high-speed steam and gas turbine rotors but I have used it successfully in a great variety of cases and do not limit its application to any kind of apparatus.

Having now particularly described and ascertained the nature of my said invention and in what manner the same is to be performed, I declare that what I claim is :—

1. The method of balancing a body which consists in rotating it on a flexible shaft or on yieldable supports and removing excess material from it by abrasion until balance is attained, substantially as described.

2. The process of balancing a body which consists in rotating it under normal working conditions, on a suitable flexible shaft, and causing it to balance by grinding off excess material from it, substantially as described.

3. The process of balancing a body which consists in rotating it on a suitable flexible shaft supported on two bearings, at a speed which is an odd multiple or submultiple of the critical and grinding off excess material therefrom, substantially as described.

4. The process of balancing a body which consists in rotating it on a suitable flexible shaft supported on one side only, at a speed which is an even multiple or submultiple of the critical and grinding off excess material therefrom, substantially as described.

5. The combined apparatus, as shown and described, for the purpose set forth.

Dated this 23rd day of August, 1921.

NIKOLA TESLA.

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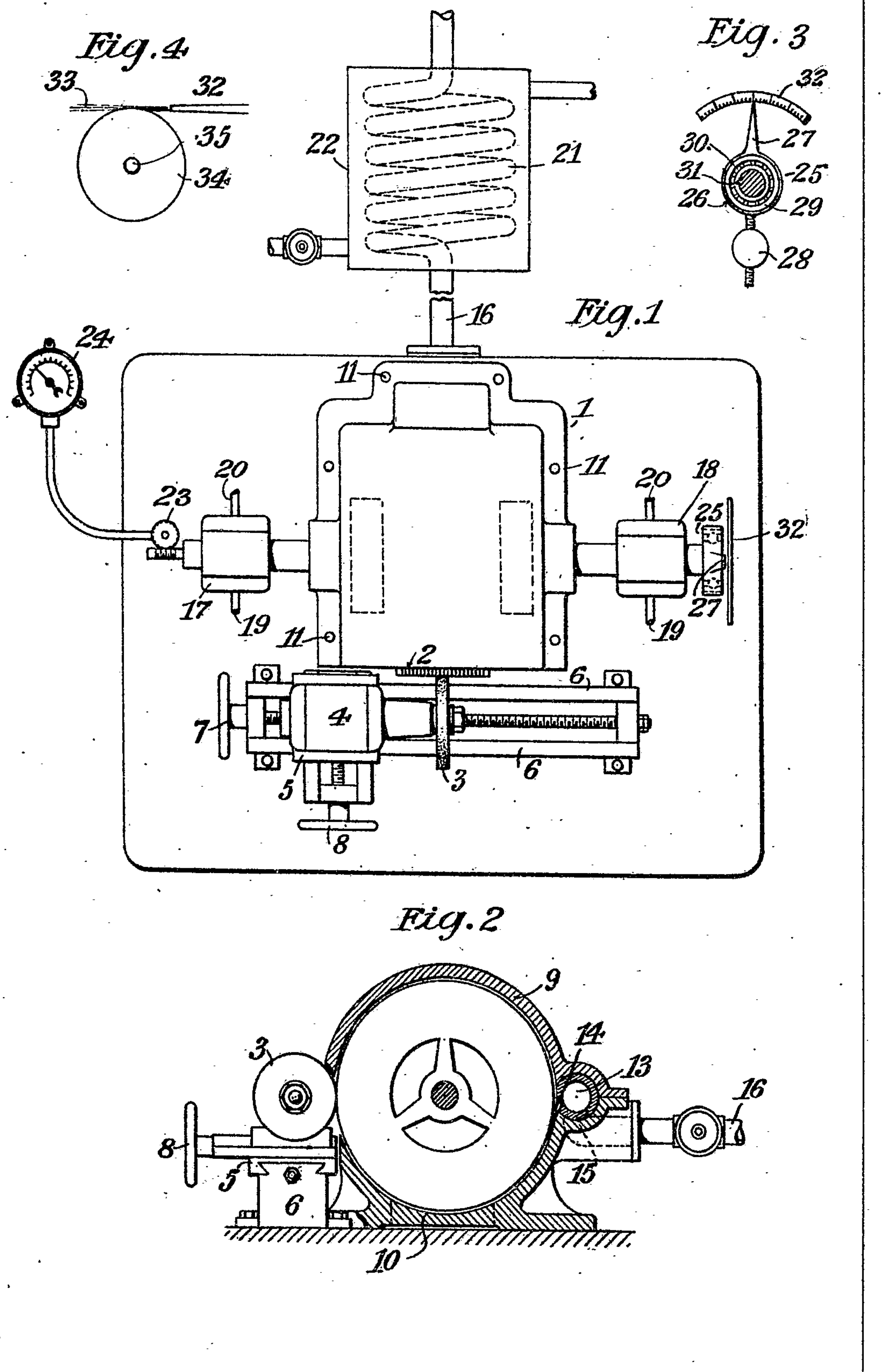
[Wt. 65—125/12/1922.]

186,799 COMPLETE SPECIFICATION

1 SHEET

2nd Edition



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