(No Model.) 5 Sheets—Sheet 1.

J. M. BRADFORD.

METHOD OF AND APPARATUS FOR REGULATING ELECTRIC CIRCUITS.

No. 535,158. Patented Mar. 5, 1895.

Fig. 1.

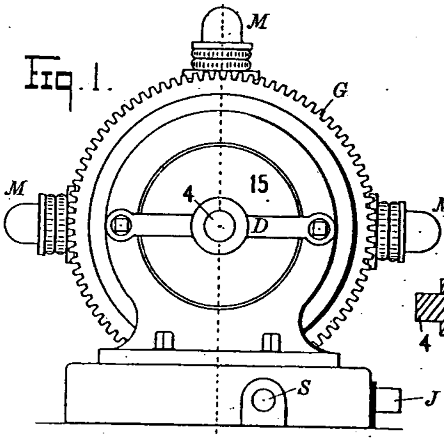


Fig. 2.

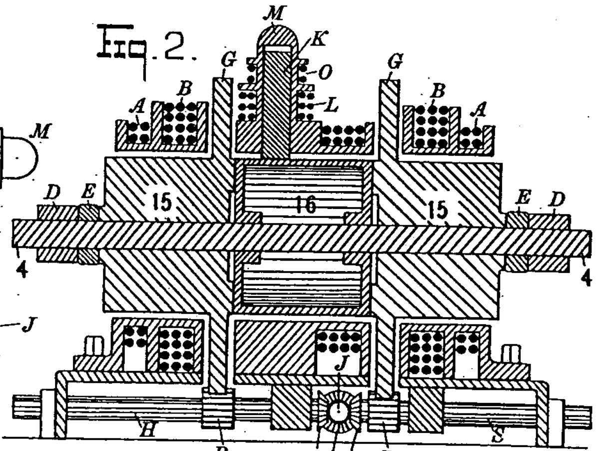


Fig. 3.

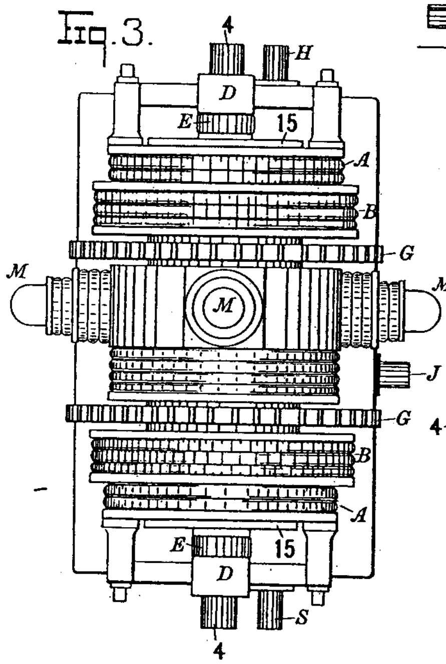
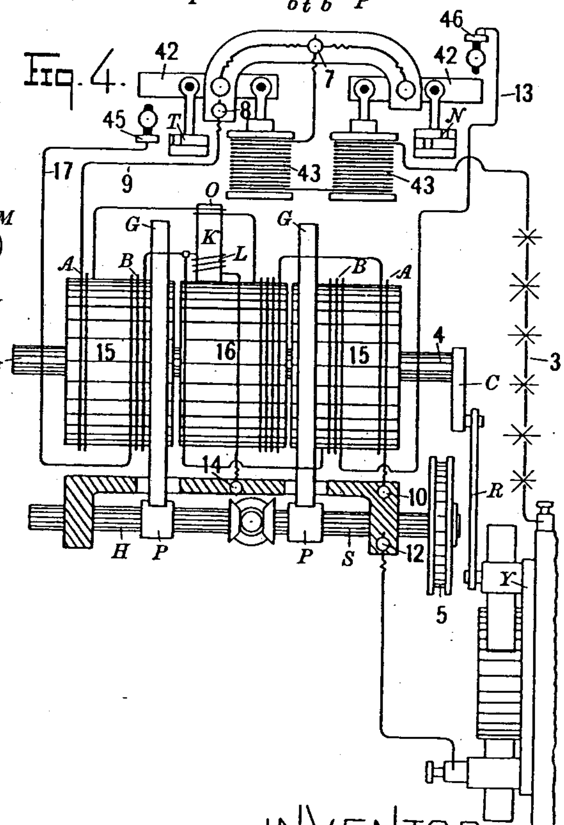


Fig. 4.



WITNESSES:

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(No Model.)

5 Sheets—Sheet 2.

J. M. BRADFORD.

METHOD OF AND APPARATUS FOR REGULATING ELECTRIC CIRCUITS.

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Fig. 5.

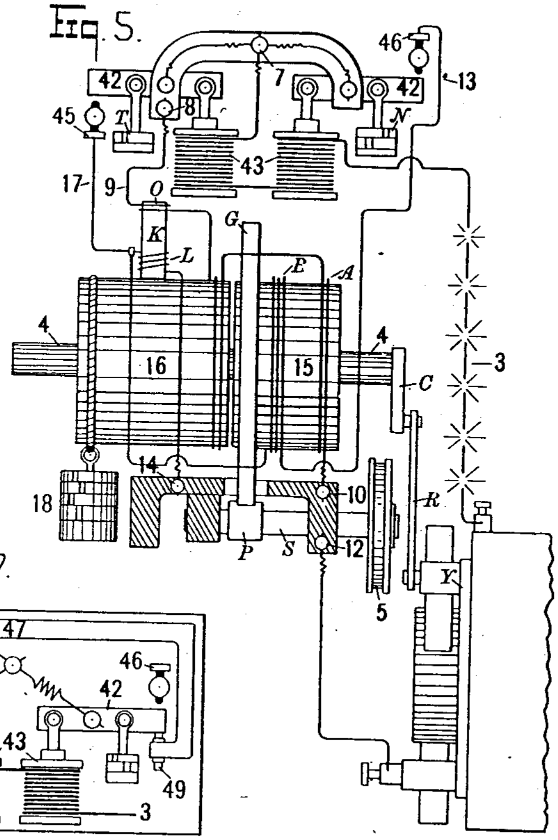


Fig. 6.

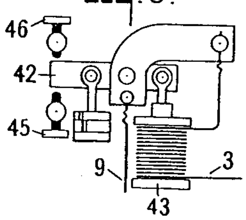


Fig. 7.

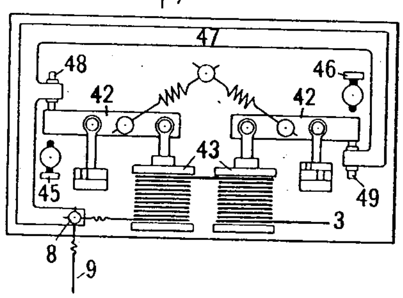


Fig. 8.

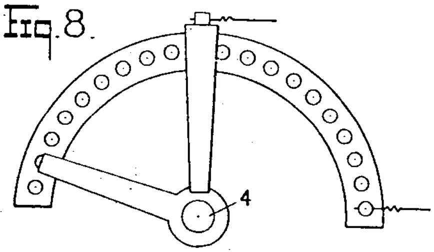
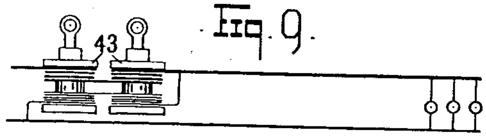


Fig. 9.



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(No Model.) 5 Sheets—Sheet 3.

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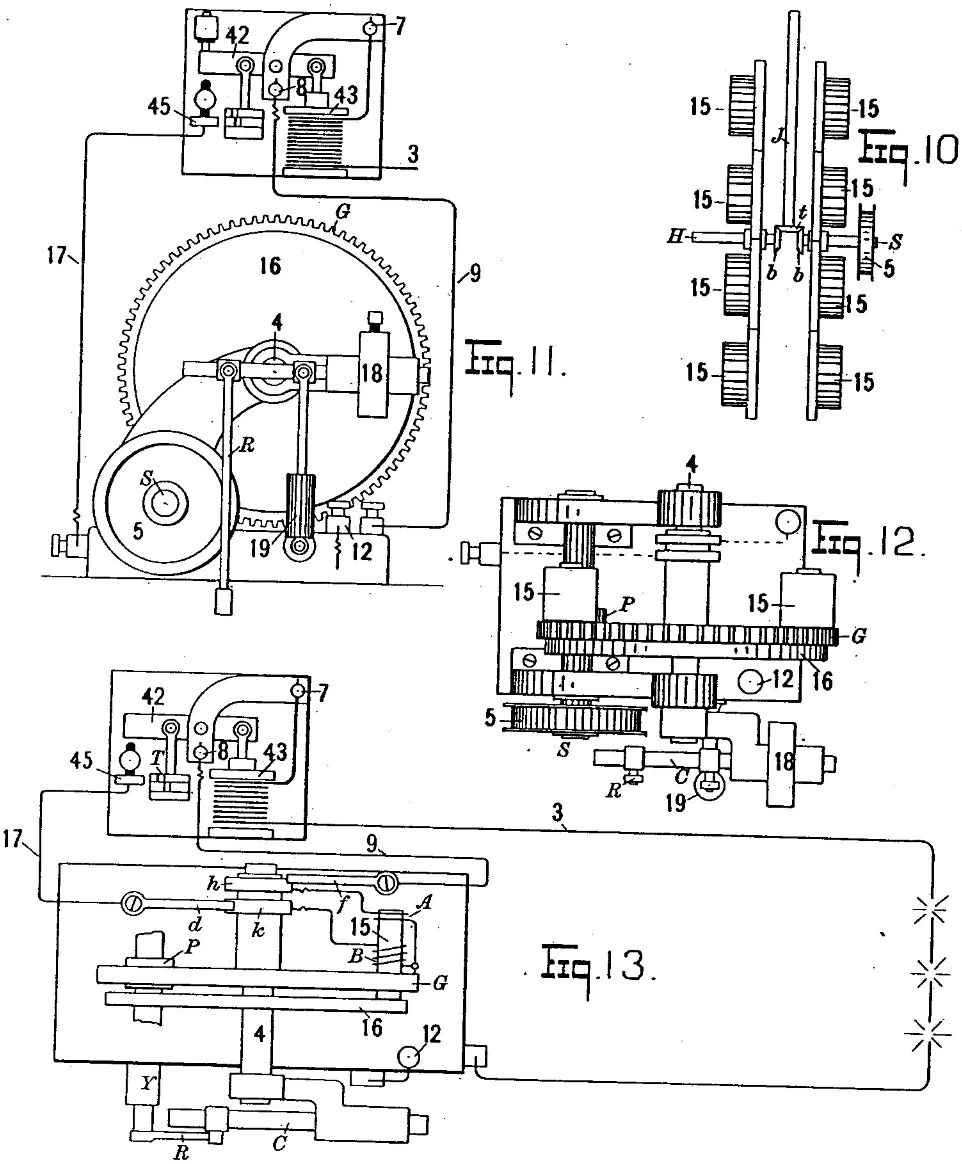
METHOD OF AND APPARATUS FOR REGULATING ELECTRIC CIRCUITS.

No. 535,158. Patented Mar. 5, 1895.



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5 Sheets—Sheet 4.

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METHOD OF AND APPARATUS FOR REGULATING ELECTRIC CIRCUITS.

No. 535,158.

Patented Mar. 5, 1895.

Fig. 17.

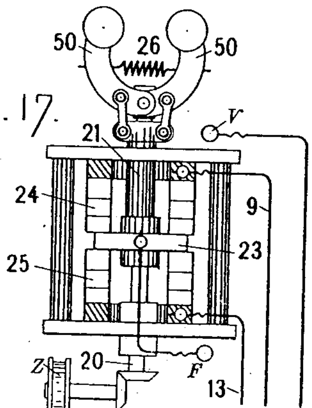


Fig. 14.

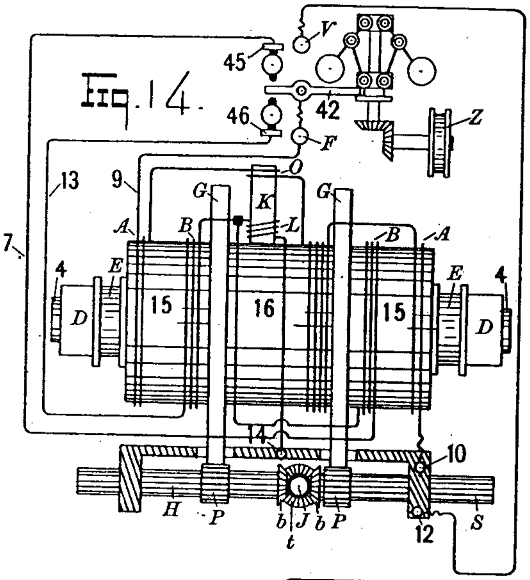


Fig. 16.

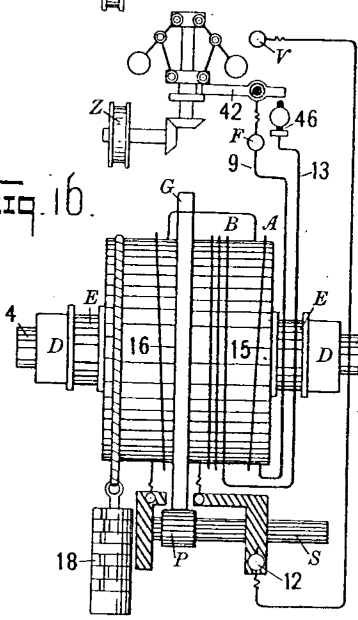


Fig. 15.

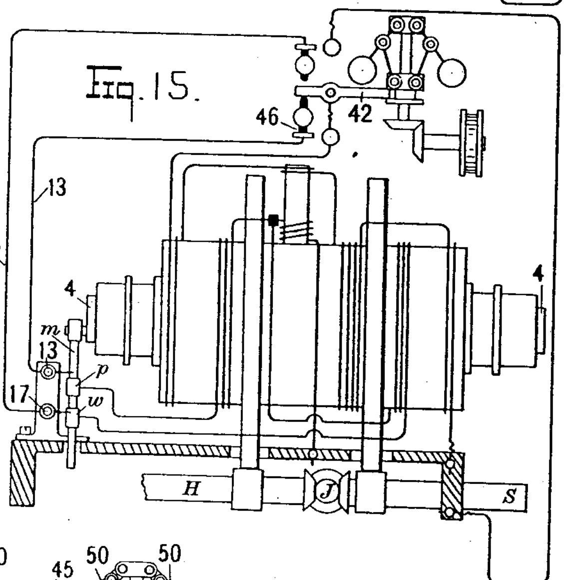


Fig. 18.

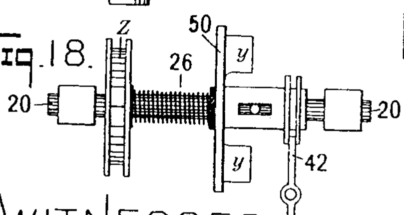
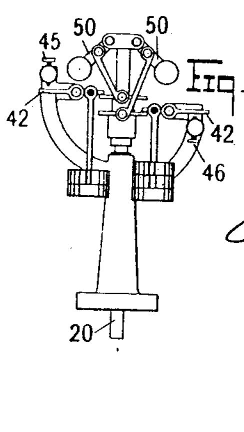


Fig. 19.



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(No Model.)

5 Sheets—Sheet 5.

J. M. BRADFORD.

METHOD OF AND APPARATUS FOR REGULATING ELECTRIC CIRCUITS.

No. 535,158. Patented Mar. 5, 1895.

Fig. 20.

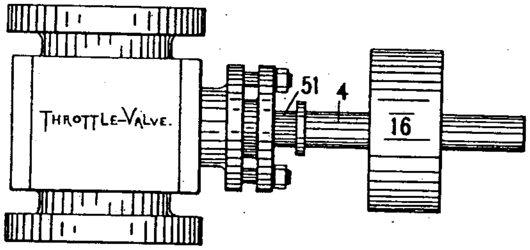


Fig. 21.

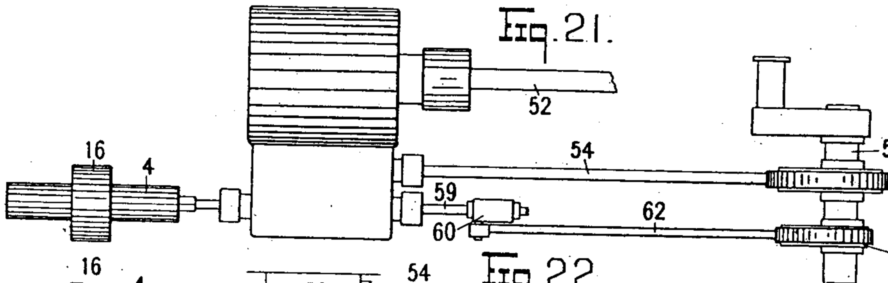


Fig. 22.

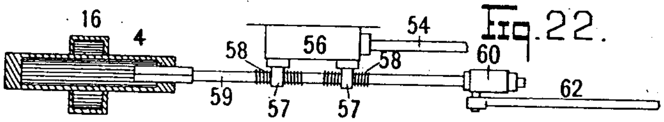


Fig. 23.

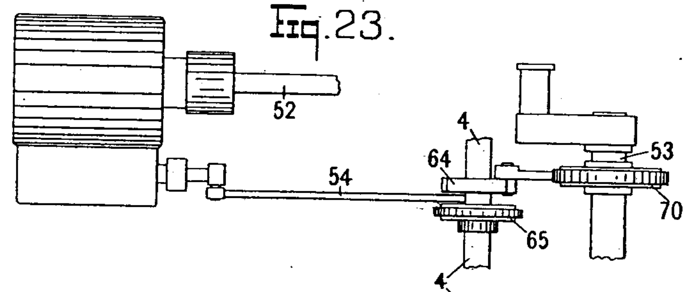
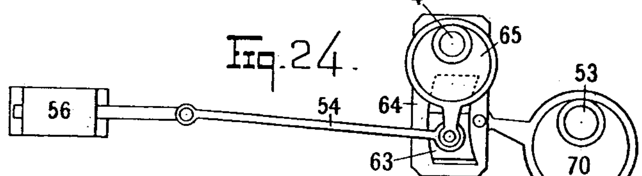


Fig. 24.



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E. H. Hosmer

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UNITED STATES PATENT OFFICE.

JULIEN M. BRADFORD, OF PORTLAND, MAINE.

METHOD OF AND APPARATUS FOR REGULATING ELECTRIC CIRCUITS.

SPECIFICATION forming part of Letters Patent No. 535,158, dated March 5, 1895.

Application filed January 9, 1894. Serial No. 496,303. (No model.)

To all whom it may concern:

Be it known that I, JULIEN M. BRADFORD, a citizen of the United States, residing at Portland, in the county of Cumberland and State of Maine, have invented a new and useful Method of and Apparatus for Regulating Electric Circuits, which is described in the following specification with sufficient clearness to enable others skilled in the art to which it appertains to make and use the same.

My invention relates to systems of electrical distribution; and the purpose thereof is to provide automatic means whereby the current upon circuits may be regulated and maintained at a certain degree, or at a substantially uniform intensity.

The invention described in the following specification is widely applicable to different systems of generating and distributing electric currents, being especially intended for use at electric lighting and power stations, to aid in the economic generation and distribution of current, thereby securing the various advantages incident to proper regulation.

This invention provides means to govern the speed of engines supplying power.

Dynamos with compound winding for self-regulation must be driven at a predetermined rate of speed in order to give the required results. The following specification describes apparatus to govern the speed of such dynamos by governing the speed of the engines by which they are driven.

The salient features of the following described apparatus include—

First. A current-varying device or commutator, designed to control the current of electricity, steam or other force producing agent requiring regulation: The current-varying device acts in one direction to increase, in the opposite direction to decrease the current which it controls. This action may be said to be progressive and retrogressive.

Second. The driving power: This power actuates the current-varying device and is derived from any convenient source, such as the engine driving the dynamo, or from a small electric motor. It is constantly expended in excess of requirements and is utilized in proportion to the extent and frequency of movements of the current-varying device. It may be called a differential power since it is expended in one direction or the reverse with different effect.

Third. The controlling power: This power governs the action of the driving-power above mentioned. It is produced by an electric current which alternates, or acts by turns, simultaneously releasing and causing movement of the current-varying device, or by reverse of such action preventing movement of said device. This also may be called a differential power since it is expended in one direction and the reverse with different effect.

Fourth. The stop-motion device: This device is operated by the controlling-power above mentioned and acts as a special means to aid in holding the current-varying device stationary while the current to be regulated is of normal force.

Fifth. Controllers: These devices govern the action of the controlling power above mentioned. They include devices responsive to variations of electric current, also to variations of engine speed and Figure 15 shows a device to limit the movement of the current-varying device. When these controlling devices break a circuit the neutralizing effect of sudden increase of the opposite acting current has tendency to prevent injurious sparks. By the arrangement shown in Fig. 17 the current is not broken, but thrown into waves of varying force. The controllers with two levers 42 are designed to prevent injurious oscillations, or to secure more nearly a dead-beat action. By the arrangement shown in Fig. 7 the action of lever 42 breaks one contact and makes a new contact at substantially the same instant, thereby preventing wheel 16 from being acted upon oppositely at the same time.

Sixth. The arrangement for independently operating several regulators by one motor: This apparatus may be used to regulate circuits for constant current, or for constant electro-motive force, according to the arrangement and requirements in different cases. To check, anticipate, or prevent, by the use of auxiliary power material development of incipient faults in the current to be regulated, is a prominent feature of this invention.

Of the drawings illustrating this invention, Fig. 1 is a front view of the regulating apparatus. Fig. 2 is a section of Fig. 1. Fig. 3

is a plan of Fig. 1. Fig. 4 is a diagram showing an application of the apparatus to a series dynamo. Fig. 5 is a diagram, showing a different form of regulating apparatus applied to a series dynamo. Fig. 6 is a side view of an electric controller. Fig. 7 is a side view of another form of electric controller. Fig. 8 is a side view of a rheostat. Fig. 9 is a diagram showing a mode of applying differential winding to an electric controller. Fig. 10 is a diagram showing a mode of working several regulators by one power shaft. Fig. 11 is a front view of a different form of regulating apparatus, also with a controller attached. Fig. 12 is a plan of Fig. 11. Fig. 13 is a diagram showing an application of the apparatus to a series dynamo. Fig. 14 is a diagram showing the apparatus arranged to govern the speed of an engine. Fig. 15 shows the apparatus illustrated by Fig. 14 with the addition of a break circuit device to limit the movement of the regulating valve. Fig. 16 is a diagram of another form of speed governing apparatus. Fig. 17 is a side view of a speed controller arranged to throw the electric current into waves of varying force. Figs. 18 and 19 are different forms of speed governors. Fig. 20 is a side view showing a mode of attaching the speed governing apparatus to the throttle valve of an engine. Fig. 21 is a plan showing a mode of attaching the speed governing apparatus to an engine with variable cut-off. Fig. 22 is a detail of Fig. 21. Fig. 23 is a plan showing a mode of attaching the speed governing apparatus to another form of engine with variable cut-off. Fig. 24 is a side view of a detail of Fig. 23.

Figs. 1, 2, 3 and 4 show a construction of the apparatus and its application to a series dynamo. The electro-magnets 15 are each encircled by coils A and B wound in opposite directions for opposite magnetic effect. Each magnet 15 is armed with a spur gear G and loosely supported upon shaft 4. The gears G engage with pinions P attached to shafts S and H. Upon the ends of shafts S and H are fixed the beveled gears *b b* engaging with a third beveled gear *t* fixed upon shaft J. The pulley 5, (Fig. 4) may be fixed to shaft S or to shaft J or H according to convenience. Power being applied to either of the above named shafts will cause magnets 15 to revolve in opposite directions. Between magnets 15 is placed wheel 16, fixed to shaft 4, which is supported by bearings D D. Wheel 16 may be made hollow for lightness, in order that the resistance which it offers to sudden starting and stopping may be small.

Magnets 15 are so adjusted upon shaft 4 that they remain very close to the sides of wheel 16, or for greater quickness of action they may be caused to remain in constant contact with wheel 16 by light pressure of elastic washers E E.

Connection is made between the brush-shifting yoke Y of the dynamo and wheel 16 by means of shaft 4, crank C and rod R.

In practice an adjustable crank C (Fig. 13) may be used in order that different degrees of movement of the brushes may be obtained by connecting rod R to different parts of the crank.

The stop-motion device consists of a brass spool M inclosing a movable iron core K. The spool M is encircled by coils O and L wound in opposite directions for opposite magnetic effect. In practice several stop-motion devices may be used for increased effect, arranged as shown in Figs. 1 and 3 and all operated by the same controlling circuits.

The main-current flows from the dynamo by wire 3, thence through coils 43 of the controller to binding-post 7 electrically connected with the two levers 42 and also with the binding-post 8, thence by wire 9 through coil A, thence through coil O of the stop-motion device, thence through the coil encircling wheel 16, thence through coil A to binding-post 10, thence through the frame of apparatus to the other pole of dynamo by way of wire attached to binding-post 12.

The above described current flows in a direction to impart to the sides of wheel 16, and the ends of magnets 15 facing the sides of said wheel the same magnetic polarity. In other words, one side of wheel 16 will be positively magnetic, and the end of the magnet 15 facing that side will also be positively magnetic. The opposite side of wheel 16 will be negatively magnetic, and the end of the magnet 15 facing that side will also be negatively magnetic. This similarity of magnetic polarity causes repulsion between wheel 16 and magnets 15. The above described current, however, flows in a direction through coil O of the stop-motion device to cause the polarity of the lower end of core K to be opposite to the polarity of the end of wheel 16 upon which it rests, thereby causing said wheel to be held stationary by magnetic attraction. The brushes of the dynamo connected to wheel 16 consequently remain stationary while the current flows in the manner above described.

If the main-current increases beyond the required degree, the right hand lever 42 is lifted into contact with screw 46, causing a current to flow from wire 13 through coil B, thence through coil L of the stop-motion device, thence to binding-post 14, thence through frame of apparatus to other pole of the dynamo by wire attached to binding-post 12. The instant lever 42 touches screw 46 the current is divided. The circuit by way of wire 13 receives one half of the current, and the circuit by way of wire 9 the other half.

The current from wire 13 reverses the polarity of right hand magnet 15 and also reverses the polarity of core K of the stop-motion device, by reason of coils B and L each having a greater number of turns than coils A and O, causing magnet 15 to grasp and core K to release wheel 16. By the grasp of revolving magnet 15, wheel 16 with brushes of dynamo attached are moved sufficiently to cause the main-current to decline and lever 42 to break contact with screw 46. The instant lever 42 breaks contact with screw 46 current ceases to flow through wire 13 and the current from wire 9 doubles in force, causing core K to grasp and magnet 15 to release wheel 16 by change of magnetic polarity. This instantly arrests motion of wheel 16 and brushes of dynamo. If the main-current falls below the required degree, the left hand lever 42 falls in contact with screw 45, causing a current to flow through wire 17 to coil B, thence through coil L of the stop-motion device, thence to binding-post 14, thence through frame of apparatus to other pole of the dynamo by wire attached to binding-post 12. This current causes core K to release, and the left hand magnet 15 to grasp and move wheel 16 with brushes of dynamo in the opposite direction to increase the main-current. The instant the main-current gains sufficient strength to lift lever 42 from screw 45, the circuit by way of wire 17 is broken, causing current from wire 9 to double in strength and motion of wheel 16 with brushes of dynamo to be arrested by destruction of magnetic attraction of left hand magnet 15 and grasp of core K of the stop-motion device, as before described.

Coils A and O neutralize magnetism at the instant a lever 42 breaks contact with screw 45 or 46. This arrangement has tendency to prevent sparks. If additional means are required for this purpose conductors of high resistance may be used to connect screws 45 and 46 with binding-post 7.

A modified form of apparatus is shown in Fig. 5. By this arrangement the main-current flows from the dynamo by wire 3, thence through coils 43 of the controller to binding-post 7, thence from binding-post 8 to coil O of the stop-motion device, thence through the coil encircling wheel 16, thence through coil A, thence to binding-post 10, thence through frame of the apparatus to other pole of dynamo by wire attached to binding-post 12. This current causes magnetic attraction between core K of the stop-motion device and wheel 16, also prevents attraction between wheel 16 and magnet 15, thereby preventing movement of wheel 16 with brush of dynamo attached as previously fully described.

If the main-current increases beyond the required degree, right hand lever 42 is lifted into contact with screw 46, causing a current to flow from wire 13 through coil B, thence through coil L of the stop-motion device, thence to binding-post 14. This current causes the stop-motion device to release wheel 16 and revolving magnet 15 to grasp and move said wheel, thereby reducing the main-current in the manner previously fully described.

If the main-current falls below the required degree, left hand lever 42 falls in contact with screw 45, causing a current to flow through wire 17 to coil L of the stop-motion device, thence to binding-post 14 and thence to the other pole of dynamo by way of frame of apparatus and wire attached to binding-post 12. This current causes the stop motion device to release wheel 16 and weight 18 to move said wheel in the opposite direction to increase the main-current. The instant the main-current gains sufficient strength to lift left hand lever 42 from screw 45, the current through wire 17 is broken, causing current from wire 9 to double in strength and the motion of wheel 16 to be arrested by grasp of the stop-motion device as before described.

The current controller is adjusted in the following manner:—The main-current flowing through right hand coil 43 produces magnetism which has tendency to lift right hand lever 42 into contact with screw 46. If an electrical pressure of two thousand volts is required to cause sufficient current to flow through the main-circuit, weight N is so adjusted that lever 42 will not be lifted into contact with screw 46 while the current does not exceed that degree of pressure. If the current exceeds two thousand volts, lever 42 is lifted into contact with screw 46, thereby completing circuit and causing the regulating apparatus to reduce the current as before explained. The weight T on left hand lever 42 is so adjusted that a current of a little less than two thousand volts is sufficient to prevent said lever from falling into contact with screw 45. If that current falls much below two thousand volts lever 42 falls into contact with screw 45, thereby completing a circuit and causing the regulating apparatus to increase the current as before explained. By this arrangement the voltage of the main-current is increased or diminished by increasing or diminishing the weight on the right hand lever 42. The weight on the left hand lever should be less than that on the right hand lever. This difference of weight, which may be increased or diminished at will, determines the limit of variation which may take place in the main-current without causing a circuit to be closed by movement of a lever 42.

The controller Fig. 6 with one lever 42 may be used instead of the double lever controller last described. In this arrangement one lever 42 makes and breaks both circuits, the midway position of the lever being determined by the magnetic power of coil 43 acting in opposition to the traction of the weight. This arrangement, commendable on the ground of simplicity of construction, has, however, tendency to disturb action of the apparatus by lever 42 oscillating between screws 45 and 46, instead of maintaining a midway position while the main-current is substantially of the right force. The magnetic power of coil 43 which lifts lever 42 out of contact with screw 45, has also tendency to throw it into contact with screw 46. Also the weight which draws lever 42 out of contact with screw 46, has tendency to throw it into contact with screw 45. When two levers 42 are used, each lever makes and breaks but one circuit. Therefore the liability of a lever closing the opposite circuit by excess of movement is avoided.

By the controller shown in Figs. 4 and 5 both circuits by the way of screws 45 and 46 might accidentally be closed at once, thereby causing magnets 15 to act oppositely at the same time. Such action might result from improper adjustment of weights N and T or from other cause. If a controller is required which is not subject to such action, the arrangement shown in Fig. 7 may be adopted. By this arrangement current flows through coils 43 to binding-post 8, thence to levers 42 by the metallic strip 47 which is in contact with the levers at 48 and 49. A movement of the right hand lever 42 completes a circuit by way of screw 46, and a movement of left hand lever 42 completes a circuit by way of screw 45, but if both levers 42 move at the same time, contact between them and metallic strip 47 is broken and neither of the above described circuits can receive current.

Besides the application to the brushes of a dynamo the apparatus is well adapted to operate a rheostat to regulate the field current of a shunt-wound dynamo, or for other purposes. The arm of the rheostat (Fig. 8) may be fixed to shaft 4 of the apparatus which is regulated by a controller suitably connected with the main-circuit.

In feeding incandescent lamps in parallel the electro-motive force is, when many lamps are burning, higher at the poles of the dynamo than at remote parts of the circuit. To cause the apparatus to maintain a current of suitable electro-motive force at a distance from the generator, the controller may be differentially wound, as shown in the diagram Fig. 9. By this arrangement a part of coils 43 are wound with coarse wire through which flows a direct current, and a small current is caused to flow in the opposite direction through the fine wire coils fed by the main conductors in the manner shown in the diagram. The number of turns of wire in both coarse and fine wire coils are adjusted to produce the required relative effect. While but little current is used in the main-circuit but little current flows through the coarse coils. Therefore the effect produced by current through fine coils is but slightly reduced. As more current flows through coarse coils to supply increased demand the effect of current through fine coils is proportionally counteracted.

In extensive systems many rheostats are often required, all of which may be operated by apparatus driven by one power-shaft as shown in the diagram Fig. 10. By this arrangement eight magnets 15 are driven by one power-shaft S. The four wheels 16, (Fig. 4,) operated by these magnets act independently of each other by reason of being governed by controllers operated by different circuits.

Regulating apparatus differing in several respects from that previously described is shown in Figs. 11, 12 and 13. By this arrangement gear G is caused to revolve constantly by engagement with pinion P connected to shaft S and pulley 5. This gear G carries one or more electro-magnets 15 wound with coils A and B substantially as before described and preferably attached near the outer edge of said gear as shown in Fig. 12. For clearness in showing the electrical connections but one magnet is shown in Fig. 13. One end of coils A B encircling magnet 15 is connected to metallic rings h k insulated from each other and also from the hub of gear G to which they are attached. The brushes d f rest in contact with rings h k. Weight 18 imparts to wheel 16 a constant tendency to move in a direction opposite to that imparted to said wheel by the adhesion of revolving magnet 15. The rod R connects crank C with the yoke Y for shifting the brushes of the dynamo. A dash pot 19 may also be attached to crank C to steady its motion. The main-current flows from one pole of the dynamo through wire 3 to coil 43, thence to binding-post 8, thence through wire 9 to brush f, thence to ring h, thence through coils A to gear G, thence through frame of the apparatus to binding-post 12, attached to the other pole of the dynamo. This strong current causes magnet 15 to adhere to and move wheel 16 with brushes of dynamo attached in the right direction to reduce the main current. The instant the main current is reduced sufficiently to allow lever 42 to fall upon screw 45 one half of said current flows through wire 17 to brush d, thence to collar k, thence to coil B and thence to the other pole of the dynamo as before described. The current in coil B reverses polarity of magnet 15 and the opposite action of coils A and B reduces magnetism sufficiently to allow weight 18 to move wheel 16 and brushes of dynamo in the opposite direction to increase the main current. The instant the main current gains sufficient strength to lift lever 42 from screw 45 coil B is released from action by rupture of circuit by way of wire 17 and at the same instant the current in coil A doubles in strength thereby again reversing polarity of magnet 15 and causing said magnet to adhere to and move wheel 16 with brushes of dynamo as before described. By this arrangement the coil encircling wheel 16 has been omitted. Magnet 15 and wheel 16 do not repel each other excepting at the instant lever 42 closes or breaks contact with screw 45. The end of magnet 15 in contact with wheel 16 may be covered with a thin plate of brass to lessen the friction caused by the poles of said magnet slipping upon the surface of wheel 16 when the magnetism is reduced to allow weight 18 to move the wheel in this manner. Weight T of the controller is so adjusted that lever 42 will not break contact with screw 45 until the main-current slightly exceeds the required degree.

While the main-current is substantially of right quantity, the alternations of current through coils A and B of magnet 15 neutralize each other, and little or no movement of wheel 16 results. If there is an excess or deficiency of that current lever 42 breaks or closes circuit for a longer time, causing wheel 16 and brushes of dynamo attached to move in the right direction to correct the fault.

Fig. 14 shows an arrangement of the apparatus for governing the speed of engines. The speed controller, or governor as it is commonly called, is driven by connecting pulley Z to the engine to be governed. The adjustment is such that lever 42 remains midway between screws 45 and 46 while the speed of engine is normal. The current to control this speed regulating apparatus is taken from any convenient source of supply, the binding-posts V and F representing the source from which it flows to the apparatus. The valve for controlling the steam driving the engine is attached to shaft 4 in the manner hereinafter described. Shaft S is connected to the engine to be governed by means of gearing, or the belt and pulley previously described may be used for this purpose. While the speed of the engine is normal, lever 42 is midway between screws 45 and 46 causing current to flow from binding-post F to wire 9, thence through coils of apparatus and back to the other pole of the circuit at V. This current causes wheel 16 to be held stationary as before fully explained. If speed of the engine declines or increases, a circuit is closed by way of screw 45 or 46, instantly causing a movement of wheel 16 as before explained, and thereby regulating speed of the engine by movement of valve attached to the shaft of said wheel. As soon as normal speed of engine is restored, lever 42 returns to midway position between screws 45 and 46, causing current from wire 9 to double in strength and wheel 16 to be held stationary as before explained.

The apparatus shown in Fig. 15 is the same as that shown in Fig. 14, save in the addition of a device to break circuits and thereby stop the motion of shaft 4 when the speed regulating valve attached thereto has moved to its extreme limit either in opening or closing. This device consists of a rod m eccentrically attached to shaft 4. Two collars p and w are fixed to and insulated from rod m. The speed regulating valve which is opened and closed by movement of shaft 4 should be so adjusted that it will be fully closed when rod m is moved downward to its lower limit as shown in the figure.

If lever 42 of the speed controller momentarily remains in contact with screw 46 after the speed regulating valve is fully closed, motion of said valve is stopped by wire 13 slipping off of collar p. On the other hand the instant the speed regulating valve is fully opened, wire 17 slips off of collar w arresting further motion of shaft 4 in that direction.

Another form of apparatus for speed regulation is shown in Fig. 16. By this arrangement the magnet 15 is driven constantly in one direction by engagement with pinion P attached to shaft S which is driven in the manner before described. Pulley Z of the speed controller is connected to the engine to be governed as before explained. If the speed of the engine increases beyond normal rate, lever 42 closes circuit by screw 46, causing a current to flow from binding-post F through lever 42 and wire 13 to coil B encircling magnet 15, thence through frame of apparatus to binding-post 12 and thence to binding-post V. This current causes revolving magnet 15 to grasp and move wheel 16 with valve attached to shaft 4 in the right direction to reduce speed of the engine. The instant normal speed of the engine is restored lever 42 breaks contact with screw 46, causing current by way of wire 9 to double in strength and wheel 16 to be instantly released from the grasp of magnet 15 by destruction of magnetic attraction before explained. Weight 18 is therefore free to move wheel 16 in the opposite direction, subject to arrest of this action the instant magnet 15 again grasps wheel 16 by reason of lever 42 falling into contact with screw 46.

Another form of speed controller which may be used with the apparatus last described is shown in Fig. 17. By this arrangement pulley Z from connection with the engine to be regulated communicates motion to shaft 20, thereby causing levers 50 to be thrown outward in proportion to speed. Levers 50 are attached to the sleeve 21, bearing upon disk 23. Above and below disk 23 is a series of carbon plates 24 and 25. Levers 50 should be so adjusted that while the engine is of normal speed the current flowing from binding-post F to disk 23, thence to the apparatus by way of wires 9 and 13 will have substantially equal force, thereby checking movement of wheel 16. If speed of the engine increases beyond normal rate, disk 23 bears with increased pressure upon carbon plates 25 and with less pressure upon plates 24. This strengthens the current flowing from binding-post F through wire 13 and weakens that flowing from same source through wire 9, thereby producing increased magnetic attraction and causing wheel 16 with regulating valve attached to be moved by revolving magnet 15 in the right direction to close the valve.

If speed of engine declines below normal rate spring 26 attached to levers 50 draws disk 23 upward causing plates 24 to receive increased pressure and plates 25 diminished pressure. This has the effect of increasing current through wire 9 and diminishing that through wire 13, thereby destroying magnetic attraction of magnet 15 and allowing weight 18 to move wheel 16 in the opposite direction to open the valve.

A speed controller with two levers 42 may be used, if desired, for reasons explained in the description of Fig. 6. By arrangement shown in Fig. 19 the arms 50 connect with separate sleeves which are moved independently of each other, each sleeve being in operative contact with the lever 42. Increase of speed causes right hand arm 50 to move lever 42 into contact with screw 46 and diminution of speed causes the left hand arm to move left hand lever 42 into contact with screw 45.

If the apparatus is used in ships where it would be subject to the disturbing influence of violent motion, a speed controller with fans may be substituted for levers actuated by centrifugal force.

An arrangement of the above kind is shown in Fig. 18 consisting of a disk 50 carrying angularly adjusted fans y which beat the air when set in motion by pulley Z and cause disk 50 to slide upon shaft 20 against the tension of spring 26 which has tendency to move said disk in the opposite direction. The disk 50 is in operative contact with lever 42 which controls circuits for the apparatus substantially as before described.

The speed regulating apparatus described in this specification may be applied to various kinds of valve gear. If used as a throttling governor, shaft 4 of either Figs. 14, 15 or 16 is connected to the valve stem 51; Fig. 20, thereby regulating the pressure of steam working the engine. Substantially the same arrangement may also be used to control the speed of water wheels, by attaching shaft 4 above mentioned to the gate admitting water to the wheel.

The apparatus is also adapted to govern the speed of engines by operating variable cut-off valves. In the arrangement shown in Figs. 21 and 22 the piston rod 52 is connected to crank on shaft 53. Rod 54 connects the slide valve 56 to eccentric on shaft 53 in the usual manner. Upon the back of slide valve 56 ride the cut-off valves 57, the position of which relative to the steam ports in the slide valve is regulated by right and left hand screws 58 on rod 59. Rod 59 is movable in the block 60, so that when this rod revolves the screws 58 cause the cut-off valves 57 to approach or recede from each other according to the direction of movement. As a means for imparting reciprocating motion to the cut-off valves, the block 60 is attached to eccentric 70 on crank shaft 53 by means of rod 62.

The apparatus shown in Figs. 14, 15 or 16 may be used to operate the variable cut-off gear shown in Figs. 21 and 22. In this case shaft 4 is hollow and loosely fits the end of rod 59 which is square in cross section. Reciprocating motion is imparted to cut-off valves 57 by motion of eccentric 70, on shaft 53 and at the same time when rod 59 revolves to the right or left by motion of wheel 16, valves 57 vary the point of cut-off of steam driving the piston.

Another form of variable cut off is shown in Figs. 23 and 24, which consists of a slide valve 56 connected to the block 63 situated in the slot of link 64. The eccentric 70 imparts reciprocating motion to link 64, rod 54 and slide valve 56. The apparatus shown in Figs. 14, 15 or 16 may be used to operate the variable cut-off shown in Figs. 23 and 24. By this arrangement link 64 is loosely supported upon shaft 4 to which shaft is fixed eccentric 65 attached to block 63. When shaft 4 fixed to wheel 16 turns to the right or left, block 63 is raised or lowered in the link 64 and the travel of slide valve 56 attached to said block is increased or diminished, thereby hastening or retarding the cut-off of steam driving the piston.

The application of my invention is not confined to valves constructed in the mann... herein particularly described. Regulating valves to which this invention may suitably be applied are of many different constructions.

Relating to the state of the art.—Automatic apparatus designed to regulate a main-current commonly consists of a current-varying-device through which passes the current to be regulated, and mechanism responsive to changes in said current to move the current-varying device in the right direction to counteract such changes.

The apparatus described in the foregoing specification differs from other apparatus for the same purpose in the means employed to cause instantaneous connection and disconnection between the current-varying device and an auxiliary motor by which it is moved in response to incipient changes in the current to be regulated.

Wheel 16 is not permanently attached to magnets 15, and as said wheel is of small weight, its inertia or tendency to resist sudden starting and stopping will be proportionally small. On the other hand, the weight and power of magnets 15 may be largely increased, thereby causing them to act with great power in controlling the motion of wheel 16, but adding nothing to its weight. Magnets 15 may act in actual contact with wheel 16. Therefore by this means the power of their grasp is enormously increased. Magnets acting in actual contact would under ordinary conditions destroy accuracy of movement of wheel 16, by lack of complete discharge of magnetism after shutting off the current, but by differential winding and alternation of the current release of the wheel is effected at the instant of change of main-current with the quickness peculiar to electric action. The same current, by alternation through differential coils is caused to make either connection or disconnection between magnets 15 and wheel 16. The instant current flows through coil B the current through coil A is greatly weakened, and the instant current through coil B is broken, the current through coil A resumes its former strength, thereby preventing waste of power in overcoming a fixed resistance and greatly increasing the effect produced by a given expenditure of current. The stop-motion device M may be used to help control the movements of wheel 16. This device releases the wheel at the same instant that it is grasped and moved by revolving magnet 15, and also grasps said wheel at the same instant that it is released by the magnet. This causes wheel 16 to offer very little resistance to motion, and at the same time prevents it from overshooting the required movement when set in motion.

My Patents No. 410,663, of September 10, 1889, and No. 429,333, of June 3, 1890, described a double acting pawl mechanism, driven by eccentrics angularly arranged on a driving shaft, capable of moving the current-varying device twice as fast as ordinary pawl mechanism. Pawls or clutches, however, consume time in springing in and out of engagement with the current-varying device which is moved by them. As commonly arranged they are attracted in one direction by a magnet acting in opposition to a spring or its equivalent which draws the pawl in the opposite direction. The spring offers a fixed resistance which must be overcome by the magnet before the pawl can be thrown into action. The power of the magnet is therefore wasted in overcoming the fixed opposition of the spring and the tendency of a pawl to act irregularly from excessive slipping increases rapidly by increasing its speed.

My Patent No. 477,637, of June 28, 1892, described a clutch in constant contact with wheel 16. This arrangement by avoiding the necessity of the pawl being moved in and out of engagement with wheel 16 promotes quickness of action and lessens waste of power, by allowing the magnet to be adjusted close to the pawl. For satisfactory working, however, by this arrangement it is necessary that the magnet and pawl be slightly separated, for without differential action of current if the magnet, pawl and wheel 16 are in actual contact with each other accuracy of movement of the wheel would be affected by retention of magnetism after shutting off the current from the magnet. Also by the above arrangement the opposition to be overcome in moving wheel 16 is fixed. It does not vanish or abate at the instant of action of the controlling current as by the operation described in this specification.

Speed governors now in use comprise two types:—governors which throttle and thereby change the pressure of steam flowing to the cylinder in accordance with the load imposed upon the engine; also governors which regulate speed by cutting off the steam sooner or later during each stroke of the piston.

In a greater part of the speed governors now in common use, force developed wholly by variations of speed is depended upon to move the valve regulating admission of steam to the engine. Therefore a development of fault in speed is depended upon to develop force to move the valve. Theoretically considered this fault might be reduced to an insignificant figure by connecting the regulating valve to the speed controller, or governor as it is usually called, through multiplying levers or gearing, so that an imperceptible movement of the governor would produce an adequate movement of the regulating valve; but this construction is open to the objection of proportionally reducing the force applied to move the regulating valve and also greatly increases its tendency to overshoot the exact movement required to bring the engine to speed. For this reason governors that are very sensitive are not very powerful and those that are very powerful are not very sensitive.

The lack of speed regulation is forcibly illustrated by marine engines driving the screw propeller which races violently when the pitching of the ship causes the screw to be partly uncovered. But few speed governors successfully use an auxiliary power to move the regulating valve, controlled by a device which simply regulates the application of the power. The drop cut-off, however, applied to the Corliss and other engines of similar type is a familiar example of the successful application of auxiliary power controlled by the governor. By this arrangement an auxiliary power works the valve gear, the speed controller or governor merely acting to determine the length of time during each stroke of the piston that the cut-off valve shall remain open; but such a cut-off is applicable only to engines of low speed. With the modern short stroke high speed engines, the piston would reach the end of the stroke before the cut-off valve could act.

To secure powerful and accurate action is the object of the invention described in the foregoing specification. The alternating current causes wheel 16 to be powerfully grasped and instantly released by turns, thereby allowing the apparatus to be driven at a comparatively high rate of speed without losing control of the regulating mechanism attached to said wheel.

I claim as my invention—

1. In an electric regulating apparatus, the combination of a current-varying device, an electro-magnet with differential winding to govern the movements of said current-varying device, electric circuits and a device responsive to variations in the current to be regulated to control action of said magnet, and driving-gear to move said current-varying device progressively

2. In an electric regulating apparatus, the combination of a current-varying device, devices governed by electro-magnets with differential windings to regulate the movements of said current-varying device, electric circuits and controllers to cause said magnets to act oppositely by turns and driving-gear to move said current-varying device progressively or retrogressively.

3. In an electric current regulator, the combination of a normally stationary current-varying device, electro-magnets to govern the movements of said current-varying device, a stop-motion device to aid in controlling the movements of said current-varying device, electric circuits and a main-current controller to cause said electro-magnets and stop-motion device to act oppositely by turns and driving-gear to move said current-varying device progressively or retrogressively.

4. The method of governing the action of a current-varying apparatus, which consists in simultaneously releasing and actuating said current-varying apparatus by differential power the instant the force of current controlled by said apparatus varies from the required degree.

5. The method of regulating an electric circuit, which consists in simultaneously releasing and actuating current-varying apparatus by differential power the instant the force of current controlled by said apparatus varies from the required degree, and in opposing action of said current-varying apparatus by alternation of said power the instant the required force of said current is restored.

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