

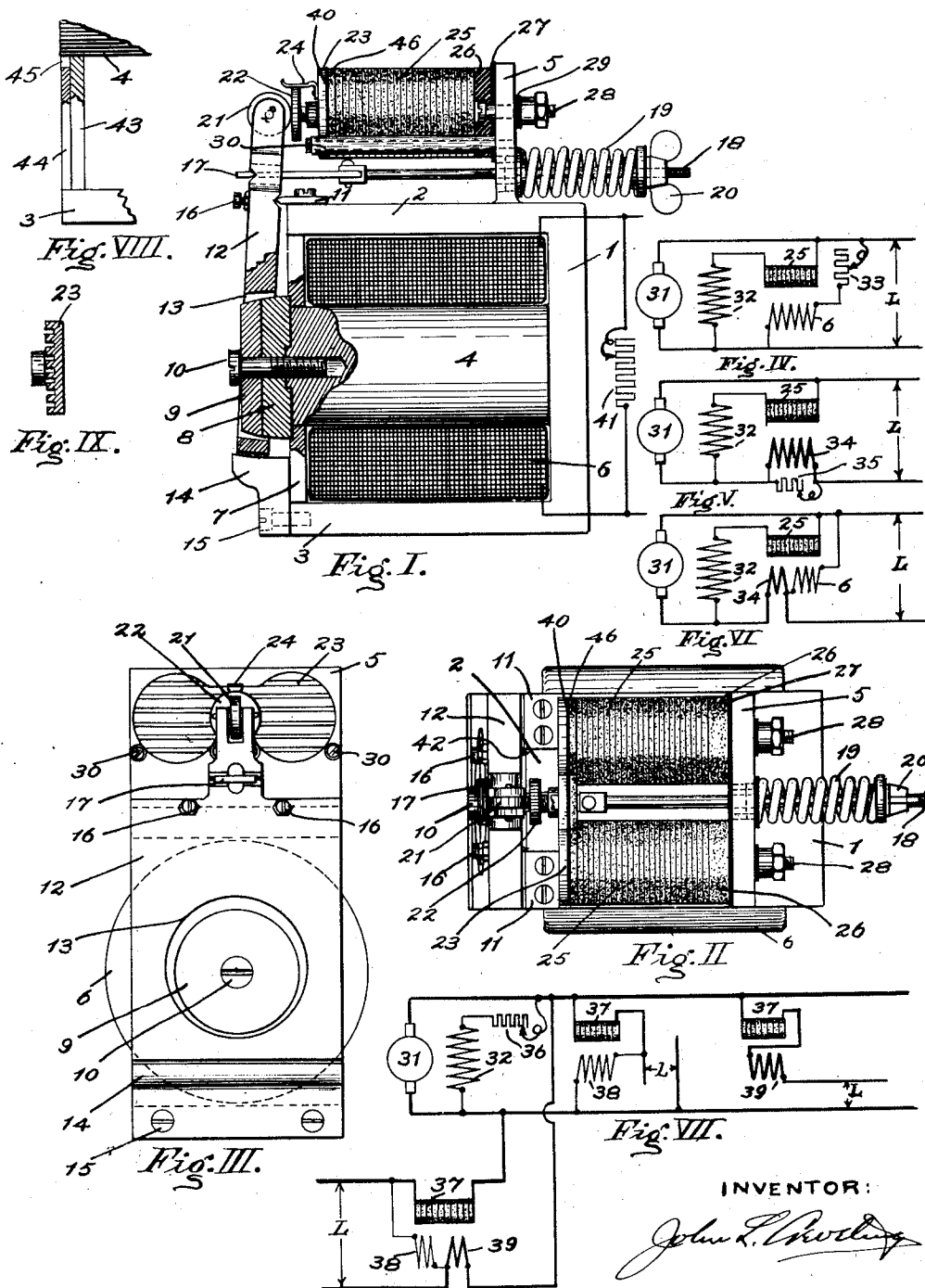
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ELECTRIC REGULATOR

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UNITED STATES PATENT OFFICE

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ELECTRIC REGULATOR

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My invention relates to that class of electric regulators used for automatically controlling the voltage impressed upon a circuit or the current flowing in a circuit, in a predetermined manner, and may be employed to affect the circuit to be regulated directly or to affect the generator supplying the circuit to be controlled.

My invention has for a particular object to provide a simple, effective, device for carrying out the above-mentioned operations, which will be delicate in operation and at the same time free from mechanical or electrical refinements in construction which are usually required in devices or apparatus of like delicacy in operation and which are responsible for the usual high cost thereof.

A further object of my invention is to produce a regulator having considerable range throughout which it will operate upon small fluctuations without "hunting" or requiring the use of a dashpot, with all of its attendant disadvantages, as is usually necessary.

A further object of my invention is to provide an automatic regulator which may be used in a shunt circuit and corrected automatically for variations in temperature, without the extravagant waste of current entailed by the usual means of making this temperature compensation. Other objects of my invention will be apparent from the following specification.

Fig. I is a side elevation and partial section of one type of regulator chosen to illustrate an embodiment of my invention; Fig. II is a top plan of the regulator of Fig. I; Fig. III is an end elevation of the regulator illustrated in Figs. I and II; Figs. IV, V, VI and VII are diagrams showing some applications of my invention to electrical systems; and Figs. VIII and IX show details of construction that may be incorporated in the structure of Fig. I.

In the drawing, referring particularly to Figs. I, II, and III, 1 represents the end portion of the main frame or body and magnetic circuit of my regulator, provided with an upper limb 2, a lower limb 3 and a core 4, and an upward extension or bracket 5, all of which being united together may be cast

integrally, of steel or other suitable material, to form the major portion of the magnetic circuit. The core 4 is surrounded by the actuating coil or coils indicated at 6, while between the limbs 2 and 3 is fitted a member 7 which also fits snugly over the end of the core 4 so as to keep the said core and the members 2 and 3 in fixed relation with respect to each other. This member 7 may be of various materials, of sufficient rigidity to fulfill the above mechanical office and, by proper selection, may be made to fulfill other offices, which will hereinafter be more fully explained. The core 4 has its outward end machined to receive and hold in position the main pole piece 8, of iron or other magnetic material, which may have placed thereupon the auxiliary pole piece 9, of a special material to perform a specific function which will hereinafter be pointed out. Both of these pole pieces may be formed substantially as indicated in the drawing and retained in their proper positions by means of screw 10. The upper limb 2 of the magnetic frame is provided with knife-edges, indicated at 11, a good arrangement for the purpose being plainly shown in Fig. II. These knife-edges engage the V-groove in the member 12, as shown in Fig. I, and serve as a practically frictionless fulcrum and support for the said member 12 which is perforated, as shown at 13, so as to form a proper airgap between 12 and the pole pieces. With pole pieces 8 and 9 of the general form indicated in the drawing, this perforation may be slightly conical, as illustrated. The lower portion of the member 12, or the armature, has separated from it by a short airgap the lower pole piece 14 which may be attached to the lower limb 3 as by screws 15. The armature 12 is held from laterally moving upon the knife-edges 11 by means of screws 16, the ends of which are pointed and engage the inside edges of the knife-edges 11, as indicated at 17 in Fig. II. 17 is a hardened steel T-shaped member, provided with a knife-edge on each side of the center, adapted to engage the V-slot or notch in the armature 12 when the longer limb of the member 17 is passed through a suitable opening in the member 12, as plainly

shown in Figs. I and III. The longer limb of member 17 is united by any suitable means, as for example the clevis shown, with one end of the rod 18 passing through the member 5 and a suitable bushing and through the compression spring 19, without touching any of said members. The other end of spring 19 is provided with a bushing, as shown engaged by the wing nut 20 whereby the force of the spring is transmitted with negligible friction to the member 12, tending to revolve it about the knife-edges 11 in a clockwise direction. The upper end of the member 12 is shown as contracted and provided with a sheave or roller 21, preferably of magnetic material. This rests upon the face of the milled-head screw 22, carried by the compression plate 23, which plate carries the spring pawl 24, engaging the milled-head 22, so as to retain the same in any position of adjustment.

In the form of my regulator here illustrated, I use two carbon piles in series as a variable regulating element, as shown plainly in Figs. II and III, and, therefore, this compression plate 23 is so arranged as to engage one end of both of the piles 25, as shown plainly in Fig. II. A carbon bridge or connecting member 46, for electrically joining the two piles 25, is preferably carried by the member 23 from which it may be insulated, as by means of a sheet of insulating material such as mica, indicated at 40. The piles 25 are compressed between the plate 23 (and its bridging member 46) and the two carbon members 26 which are insulated from the standing member or bracket 5, as by means of a sheet of insulating material 27 such as mica or other material capable of withstanding considerable heat. The binding screws 28 connect with each of the heavy carbon disks or terminal members 26, as indicated in Fig. I, the screws, of course, being insulated from the member 5, as by means of bushings indicated at 29. Piles 25, together with the bridge member 46 and compression plate 23, may be supported and held in their proper positions in any suitable manner, and, in this instance, are indicated as resting upon four glass tubes 30, supported by screws made up into the bracket 5.

From the foregoing it will be plain that the piles 25 may be held under a chosen degree of compression by proper selection of the spring 19 and proper adjustment of the nut 20, and that excitement of the coil 6 will cause magnetic lines to be set up in the core 4 which may pass through the pole pieces 8 and 9 and across the annular airgap defined at 13, into the armature member 12; and that part of these lines may travel upwardly through the member 12 and across the gap between it and the member 2 and back to the core; while another part of the lines may travel from the pole pieces 8 and 9 across the airgap to the

lower portion of the armature 12, and thence across the airgap to the pole-shoe 14, from which return is made through the lower limb 3 and the back member 1 to the core 4. And it will be plain that these lines (whether of the polarity above mentioned or the reverse thereof) will tend to swing the armature 12 in a counter-clockwise direction around the knife-edges 11, against the action of spring 19, to gradually reduce the reluctance caused by the air gaps, and by such movement relieve the pressure upon the piles 25 so as to increase the resistance thereof. It will also be plain that the normal position of the armature 1 with respect to the pole pieces 8 and 9 may be roughly adjusted by choosing the proper length of piles 25, and finely adjusted by turning the milled nut 22 so that its threaded stem will travel in the boss shown upon the compression plate 23. The compression plate 23 is preferably made of aluminum, or other material possessing requisite strength with as little weight as possible, and, while shown as a plain member in Fig. I, is preferably grooved or webbed, as shown in Fig. III, or as shown in section in Fig. IX, so as to more readily dissipate the heat conducted away from the carbon piles.

With the pole piece 8 alone in the structure of Fig. I, that is, assuming the pole piece 9 to be removed, it will be obvious that nearly all of the magnetic lines will cross the short airgap to the armature 12, in such manner as to cause an attraction of the armature, though, of course, some lines will leak from the pole piece 8 to the left-hand face of the armature in such manner as to contribute nothing to the pull, while some will tend (on account of leakage) to actually lessen the pull upon the armature. The addition of the pole piece 9, which may actually extend through the armature 12, will, of course, increase this leakage flux and may be so shaped that it will require more ampere turns in the coil 6 to move the armature 12 against the action of spring 19 with the pole piece 9 in place, provided this be of magnetic material, than are required with the pole piece 9 omitted. Therefore, if the pole piece 9 be made of a material the magnetic permeability of which may be varied, the number of ampere turns required in the coil 6 to produce a given result may be also varied within certain limits. If we assume the coil 6 to be a shunt coil, and the spring 19 so adjusted that a desirable effect upon the pile 25 is produced when the coil 6 is cool, as when the regulator is started in operation, it is obvious that as the regulator continues in operation the coil 6 will become heated and its temperature will rise until a certain steady state is reached, when the resistance of the coil will be appreciably greater than when it was cool; and it will, therefore, in a shunt circuit, receive less current at a given voltage than before, and

the adjustment of the regulator will be interfered with so that it will now require a higher voltage across coil 6 than before to produce the desired effect above mentioned.

5 As the coil 6 becomes heated, it gives up considerable of its heat to the core 4, which being a good conductor of heat causes the pole pieces 8 and 9 to have their temperature raised as the temperature of the coil 6 increases.

10 As the pole piece 8, or the main attracting pole piece, is made of iron or a proper grade of steel that this rise in temperature will not materially affect its permeability, the difference in pull caused by the magnetic lines emanating from the pole

15 piece 8 will not be materially affected by the heat thus generated, except in so far as the heat cuts down the magnetizing effect of the coil 6 by increasing its resistance. On the

20 other hand, by making the pole piece 9 of a nickel steel alloy, containing substantially thirty per cent nickel, this pole piece when cool will have a relatively high permeability which will decrease as it becomes heated until

25 very low, even at a temperature at which it is safe to operate the coil 6. As this loss in permeability of the pole piece 9 causes less ampere turns to be required in the coil 6 to produce the above-mentioned desired result,

30 it will be obvious that by proper arrangement of the pole piece 9 the rise in resistance of the coil 6, due to its rise in temperature, may be compensated for by the falling off in permeability of the pole piece 9 upon such rise, due

35 to the transfer of heat from the center or hottest part of the coil to the said pole piece 9. Or, if preferred, the member 7 of Fig. I may be made of an alloy the permeability of which decreases upon increase in temperature,

40 as for example the nickel steel alloy above mentioned; and then, if chosen of proper dimensions, it may be made to compensate for the rise in temperature of the coil 6, because when cool the member 7 will shunt

45 a certain portion of the lines from the core 4 to the limbs 2 and 3 and away from the pole piece 8, which shunting effect will fall off as the piece 7 becomes heated and its permeability decreases. It will be obvious that either

50 the compensating pole piece 9 or the compensating member 7 may be used alone, or they may be used together to carry out the temperature compensation, which may be controlled by the proper selection of shape, dimensions and material of the members; also

55 that instead of the member 7 entirely bridging the space between the core 4 and the return limbs of the magnet, an airgap may be introduced, as for example as shown at 45

60 in Fig. VIII, where a compound member is shown in place of the simple member 7 of Fig. I. It will also be plain that the magnetic shunt may be the member 44 of Fig. VIII only, while the member 43 may be of

65 non-magnetic material and serve to hold the

relationship between the core 4 and the limbs 2 and 3 mechanically, without affecting the magnetic circuit; or members 43 and 44 may be both of magnetic material, and either one or both affected upon temperature changes

70 to produce compensation, as above pointed out, either alone or in combination with any other compensating means, as for example the pole piece 9.

An operation of my improved regulator

75 may be understood from the following: In Fig. IV, the regulator is diagrammatically represented as controlling the generator 31 to hold constant voltage upon the line supplying the load indicated at L. It does this

80 by controlling the current in the field coil 32, by varying the resistance of the piles 25, here indicated as in series with the said field coil, the regulator being operated by a voltage coil 6 of fine winding, placed across

85 the load circuit through a resistance 33, if desired to provide additional adjustment, as will hereinafter be pointed out. With a generator intended to be operated at substantially constant speed, it is often desirable

90 to normally operate the same at a little higher speed than necessary to produce the chosen line voltage and bring the generator to the proper voltage by so adjusting the

95 spring 19 and the resistance 33, if the same be used, that the coil 6, by attracting its armature 12, will slightly relieve the pressure upon the piles 25 so as to insert some

100 resistance in the field circuit. Then if the generator speed falls a little, or its voltage tends to drop for any other reason, the drop in voltage across the coil 6 will allow the

105 spring 19 to increase the pressure upon the piles 25 and raise the voltage of the generator up to the standard; while, on the other hand, if the generator speed tend to increase

110 above the normal, even to several times the normal operating speed (as in systems employing a variable speed generator), I can still hold the voltage substantially constant

115 upon the system, because, as the voltage tends to rise, a very slight increase will cause the armature 12 to be drawn in toward core 4 and relieve the pressure upon piles 25 and

120 increase their resistance so as to cut down the field current in coil 32 and hold the generator voltage substantially constant throughout these changes. And I find that, by properly shaping the pole piece 8, or

125 the pole pieces 8 and 9 when both are used, and the opening 13 in the armature 12, I can cause the generator voltage to be held substantially constant, with this apparatus, within very narrow limits; while, at the same

130 time, "hunting" may be avoided throughout an extremely wide range of operation by proper shaping of the pole pieces and armature opening and proper selection and adjustment of the spring 19. Of course, the

member 7, which tends to hold the core 4 and the limbs 2 and 3 in their proper relative positions, by being made of a conducting material will serve as a short-circuited secondary winding upon the core 4 and cooperate in tending to damp out any tendency toward "hunting", for which reason it is advantageous under certain conditions to make this member partly, if not wholly, of copper. Furthermore, when the regulator is used as indicated in Fig. IV, with a resistance 33 in circuit, very fine adjustment of the coil 6 may be accomplished by using a shunt of relatively high resistance, as indicated at 41 in Fig. I, and when this is used it will also assist in the prevention of "hunting".

With the apparatus operating as above described in connection with Fig. IV, the current flowing in the coil 6 will, by increasing its temperature, raise its resistance and, therefore, somewhat diminish the current in the operating coil and tend to change the adjustment of the regulator as the same continues to have its temperature varied; but, this causes a very rapid transferring of heat to the core 4, pole piece 8 and pole piece 9, and also the member 7, whereupon if the pole piece 9 be made of nickel steel, as above pointed out, its permeability will fall off and tend to compensate for the falling off in current in the coil 6, as above pointed out, in such manner as to substantially compensate for this rise in temperature of the coil. Or, if the member 7, or a portion thereof, be made of proper material, such as the nickel steel above mentioned, this may serve to compensate for this temperature rise, as pointed out above in the description of said member. In the event that it be desired to cause further compensation than is readily brought about by either one of these heat responsive members or elements, it is obvious that they may be used together to cooperate to maintain a fixed adjustment of the regulator throughout temperature changes. And it will further be plain that, if the resistance 33 be used, it may not only perform the function of adjustment of the coil 6 or operation of the regulator, but, if made of a material such as the well-known "advance" wire having a zero temperature coefficient, it will also assist in compensating for temperature changes, though it does so at the expense of a heat loss which it is advantageous to hold as small as possible. It is not deemed necessary to explain how the resistance 33 can thus assist in temperature compensation as this method is now so widely used for this purpose, though extremely wasteful when performing the entire compensation.

In Fig. V, the regulator is indicated as affecting the generator in the same manner as in Fig. IV, but in this case it holds the

current supplied to the load L constant, instead of the voltage as in Fig. IV, since the regulator is operated by a current coil, indicated at 34, across which a variable shunt 35 may be placed for the purpose of adjustment, which if non-inductive will also assist materially in preventing any tendency of the regulator toward "hunting"; and it is believed that the operation of the regulator, in the environment of Fig. V, is so obvious from the description above that it will need no further explanation than to point out that the series coil 34, by affecting the resistance 25, holds the generator current substantially constant throughout changes in speed of the generator or variations in the resistance of the load L. It is, of course, obvious that when the regulator is operated by a series coil no compensation for temperature changes is required.

In Fig. VI, the regulator is diagrammatically shown as adapted to maintain compound regulation and affected by the voltage coil 6 so as to tend to hold constant voltage, which may be modified by the current in the coil 34, or the regulator may be affected by the coil 34 to hold substantially constant current in the line, which may be modified or adjusted by the voltage upon the coil 6, depending upon the proportioning of the said windings; since it will be plain that the resultant effect of the coils 6 and 34 will control the generator by varying the resistance of piles 25.

In Fig. VII, the generator 31 is shown as having its field coil 32 adjusted as by means of a manually operated variable resistance 36, while three of my regulators are diagrammatically shown as controlling three supply circuits by directly affecting the resistance 37 in series with each of the said circuits. In one application in this figure, the regulator is shown as operated by the shunt coil 38 across the circuit having the load L, upon which constant voltage is to be maintained regardless of fluctuations that may take place in the mains or load, so long as the voltage across the mains remains above a certain value. And the coil 38, operating in the same manner that the voltage coil 6 of Figs. I and IV operates, holds the voltage constant upon this circuit whenever it tends to exceed a predetermined maximum, by increasing the resistance 37 in an obvious manner, in view of the foregoing. And, if 37 has had its value increased upon a rise in voltage across the mains, the coil 38 will cause the same to be decreased upon any fall in voltage across the mains, in such manner as to tend to hold the voltage upon the load constant, in a manner now well-known in the art.

In this Fig. VII, another application is indicated wherein the regulator is operated by a series coil 39 which carries the load L and which, by manipulation of the resistance

37, holds the current in the load circuit constant throughout changes in voltage across the mains or in the resistance of the load, so far as this can be accomplished by the manipulation of a series resistance, as will be understood. Another application in this figure shows the regulator as operated by a compound winding comprising a voltage coil 38 across the load and a current coil 39 in series therewith, and it will be obvious that either of these coils may be the dominating coil for operating the resistance 37 and have its effect modified by the other, and that the resultant effect of these coils will so manipulate the resistance 37 as to hold a substantially constant current in the load circuit modified by the voltage, or a substantially constant voltage across the load circuit which may be modified by the current supplied thereto, in so far as this regulation may be accomplished by manipulation of the series resistance 37.

In practice, I usually find it advisable to make all of the air gaps in this regulator as small, i. e., short in the direction of the magnetic lines, as can be conveniently done, as this increases the inductance and makes for stability in operation; and I usually prefer to work the magnetic circuit at a moderate density. With the type here shown it is usually preferable to make the sheave or roller 21 and the milled head of the screw 22 of iron or other magnetic material so that the stray field, by causing these two members to be attracted, will cause the plate 23 to follow the movement of the armature 12 as the pile is released.

Referring to the application of this regulator indicated in Fig. IV, for example, it may be advantageous or desirable for certain uses to allow the voltage upon the load to rise slightly as the speed of the generator increases above its normal or its lowest operating standard, and I find this is readily accomplished with this structure by so proportioning and adjusting the parts that the normal voltage across coil 6 does not quite balance the pull of the spring 19, as modified by the elasticity of the pile 25, as the armature 11 is drawn in by the flux affected by the form of pole piece 8 or pole pieces 8 and 9. I find it a very simple matter to adjust this increment of voltage as the speed increases by proper shaping of the pole piece or pole pieces and choice and adjustment of the spring 19, and proper positioning of the armature 12 as by adjusting the milled headed screw 22; and I find such an arrangement exceedingly stable as well as quick in operation, it here being noted that, with the air gap 13 of general form indicated in Fig. I of the drawing, for example, the increment of useful magnetic pull upon the armature, per increment of counter-clockwise rotation thereof, may be decreased by decreasing the diameter of the

right-hand portion of the pole piece 8, or vice versa. I also find that the voltage across the load L, with the application of this regulator as indicated in Fig. IV, for example, may be held very nearly constant throughout all changes in speed of the generator, for example, above a certain critical speed, by so proportioning the shape of the pole piece 8 or pole pieces 8 and 9, and so choosing and adjusting the spring 19 that its effect as modified by the elasticity of the pile 25 will balance the pull upon the armature 12, in all positions of operation, when the voltage across the coil 6 is at the normal desired value. With this arrangement, the voltage is accurately maintained and the regulator remains stable, even though damping devices be omitted.

I also find that it is possible with this regulator, in the environment of Fig. IV, to cause the generator voltage to fall in a predetermined manner, within certain limits, upon increases in speed above the normal value, if this be desired, by so proportioning and arranging the parts that as the armature 12 is moved inwardly to reduce the pressure upon the pile 25, the pull increases more rapidly than the opposing effect of the spring 19, as modified by the elasticity of the pile 25; and that even with this arrangement or adjustment I can, within certain limits, cause this regulator to operate in a stable manner without "hunting" and without the employment of any damping devices, while the limit to which this decrease in voltage can be brought about without causing "hunting" can be increased, if the same be desired, by the addition of damping devices, as have been above described. It will be obvious that analogous adjustments of the regulator may be made in the various other applications or uses of the same, some of which have been here indicated.

From the foregoing, it will be plain that I have produced a very simple type of regulator, capable of performing a large number of regulating functions, which is very simple in its construction and mode of operation, and is very slightly and, in fact, negligibly affected by friction. It will also be seen that, by proper design and adjustment of the parts, it may be made to operate with almost any desirable degree of accuracy and, throughout wide range, will require none of the usual mechanical damping means or devices with their attendant friction. It will also be seen that my regulator consists of but few parts, which are readily made and require a minimum of accurate machine work, and that such as is required may be readily accomplished and easily duplicated by means of jigs. It will also be seen that I have produced a regulator wherein temperature changes are automatically and inherently compensated for by small expenditure of energy.

I do not in any way limit myself to any of

the constructions shown or described or to the exact mode of operation outlined above, for it is obvious that wide departure may be made in the way of construction of the apparatus as well as in the mode of operation without departing from the spirit and scope of my invention which is as set forth in the following claims:

1. In an electric regulator comprising a nearly closed magnetic circuit with a plurality of small air gaps therein which are gradually affected by operation of the regulator to cause stable regulative operation throughout wide range, integral means normally increasing the flux through some of said gaps for compensating for the effects of temperature changes upon the operation of said regulator.

2. In an electric regulator, operating means comprising a nearly closed magnetic circuit with a small air gap therein which is gradually affected by operation of the regulator to cause stable regulative operation throughout wide range, integral means for increasing the range of stability and compensating for the effects of temperature changes upon said regulator.

3. An electric regulator comprising regulating means and operating means therefor including a nearly closed magnetic circuit with a small air gap therein which is gradually affected by operation of the regulator to cause stable regulative operation throughout wide range and integral means for inductively increasing the range of stability and compensating for the effects of temperature changes upon said regulator.

4. An electric regulator comprising regulating means and operating means therefor including a nearly closed magnetic circuit with a small air gap therein which is gradually affected by operation of the regulator to cause stable regulative operation throughout wide range and integral means for compensating for the effects of temperature changes upon the operation of said regulator by changes in permeability brought about by said temperature changes.

5. An electric regulator comprising a substantially E-shaped magnetic frame and a movable armature completing the magnetic circuit through the three parallel members thereof and carried by one of said parallel members upon a substantially frictionless fulcrum and perforated to receive one of said members and leave an air gap around the same.

6. An electric regulator comprising a substantially E-shaped magnetic frame, a movable armature completing the magnetic circuit through the three parallel members thereof and carried by one of said parallel members upon a substantially frictionless fulcrum and substantially frictionless resilient means tending to revolve said armature

about said fulcrum, said armature being perforated to receive the middle member of the frame and separated therefrom by an annular airgap.

7. An electric regulator comprising a compression resistance element, a substantially E-shaped magnetic frame and a movable armature completing the magnetic circuit through the three parallel members thereof carried upon a substantially frictionless fulcrum and substantially frictionless resilient means tending to rock said armature about said fulcrum to increase the pressure on said element and increase the reluctance of said magnetic circuit, to maintain substantial constancy of the function controlled by said regulator.

8. An electric regulator comprising a substantially E-shaped magnetic frame and a movable armature completing the magnetic circuit through the three parallel members thereof carried upon a substantially frictionless fulcrum and substantially frictionless resilient means tending to rock said armature about said fulcrum and increase the reluctance of said magnetic circuit and a regulating element affected by said rocking, to maintain substantial constancy of the function controlled by said regulator.

9. A regulator comprising three substantially parallel magnetic members joined at one end by a yoke of magnetic material, a winding upon the middle member, and an armature completing the magnetic circuit through said members and separated therefrom by short air gaps so related as to maintain inherent stability of operation, one of said gaps being variable and substantially annular.

10. A regulator comprising three substantially parallel magnetic members joined at one end by a yoke of magnetic material, a winding upon the middle member, an armature completing the magnetic circuit through said members and separated therefrom by short air gaps and a regulating element affected by said armature, all so related as to cooperate to maintain inherent stability of operation.

11. Means for regulating an electric circuit comprising an element the manipulation of which affects the electrical condition of said circuit, a movable magnetic member for manipulating said element and affected by a plurality of magnetic fluxes in shunt relation to each other therethrough, and means for opposing the effect of said fluxes in the movement of said member, all in such relation to each other that the resultant effort of said fluxes is substantially balanced in stable operative relation in all operating positions of said movable member.

12. Means for regulating an electric circuit comprising an element the manipulation of which affects the electrical condition

of said circuit, a movable magnetic member for manipulating said element and affected by a plurality of magnetic fluxes in shunt relation to each other therethrough, means for opposing the effect of said fluxes in the movement of said member, all in such relation to each other that the resultant effort of said fluxes is substantially balanced in stable operative relation in all operating positions of said movable member, and means for maintaining said fluxes.

13. Means for regulating an electric circuit comprising an element the manipulation of which affects the electrical condition of said circuit, a movable magnetic member for manipulating said element and affected by a plurality of magnetic fluxes in shunt relation to each other therethrough, means for opposing the effect of said fluxes in the movement of said member, all in such relation to each other that the resultant effort of said fluxes is substantially balanced in stable operative relation in all operating positions of said movable member, and means for maintaining said fluxes and causing them to be affected by fluctuations in the circuit to be regulated.

14. Means for regulating an electric circuit comprising an element the manipulation of which affects the electrical condition of said circuit, a movable magnetic member for manipulating said element and affected by a plurality of magnetic fluxes in shunt relation to each other therethrough, means for opposing the effect of said fluxes in the movement of said member, all in such relation to each other that the resultant effort of said fluxes is substantially balanced in stable operative relation in all operating positions of said movable member, and means for maintaining said fluxes and causing them to be affected by fluctuations in the circuit to be regulated and by the manipulation of said element.

15. An electric regulator comprising a compressible pile and electromagnetic operating means therefor including a nearly closed magnetic circuit with an airgap of small reluctance therein said elements having their characteristics cooperating and mutually affected by operation of the regulator to cause substantially constant regulation and sufficient inherent damping to produce stable regulative operation throughout wide range.

16. A regulator for controlling an electrical function comprising an element affecting said function, a winding affected by said function, a field frame magnetically affected by said winding, an armature cooperating with said field frame to form a magnetic circuit of low reluctance and movable with respect to said frame to affect said element affecting said function, means tending to move said armature to affect said element in

a given direction, said armature being separated from said frame by a plurality of cooperating airgaps the total reluctance of which is increased when the armature is thus moved, said armature being attracted by the magnetic effect of said winding to reduce the total reluctance of said gaps and vary the inductance of said winding and magnetic circuit and manipulate the element affecting said function, said manipulation and said varying of inductance having sufficient difference in natural periodicity to eliminate oscillation of said armature.

17. An electric regulator comprising a carbon pile and electromagnetic operating means including a nearly closed magnetic circuit with a small reluctance airgap therein which is gradually affected by operation of the regulator, said parts being proportioned and arranged to inductively cause inherent stable regulative operation in response to small fluctuations throughout wide range.

18. An electric regulator comprising a regulating element affected by pressure and electromagnetic pressure-varying means including a nearly closed magnetic circuit with a plurality of small reluctance airgaps therein the total reluctance of which is gradually affected by operation of the regulator, said parts being proportioned and arranged to cause inherent stable and substantially constant regulative operation throughout full range of said regulating element.

19. An electric regulator comprising a carbon pile and electromagnetic operating means including a nearly closed magnetic circuit with a plurality of cooperating airgaps of low reluctance therein which are gradually affected by operation of the regulator, said parts being proportioned and arranged to inductively cause inherent stable regulative operation in response to small fluctuations throughout wide range.

20. An electric regulator comprising a regulating element and electromagnetic means for affecting said element including a nearly closed magnetic circuit with a plurality of small reluctance airgaps therein the reluctances of which are gradually affected by operation of the regulator, said parts being proportioned and arranged to so vary the magnetic characteristics of said circuit as to cause inherent stable and substantially constant regulative operation throughout full range of said regulating element.

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