

Jan. 12, 1937.

F. W. GODSEY, JR

2,067,604

ELECTRIC REGULATION

Filed Jan. 21, 1935

2 Sheets-Sheet 1

Fig. 1.

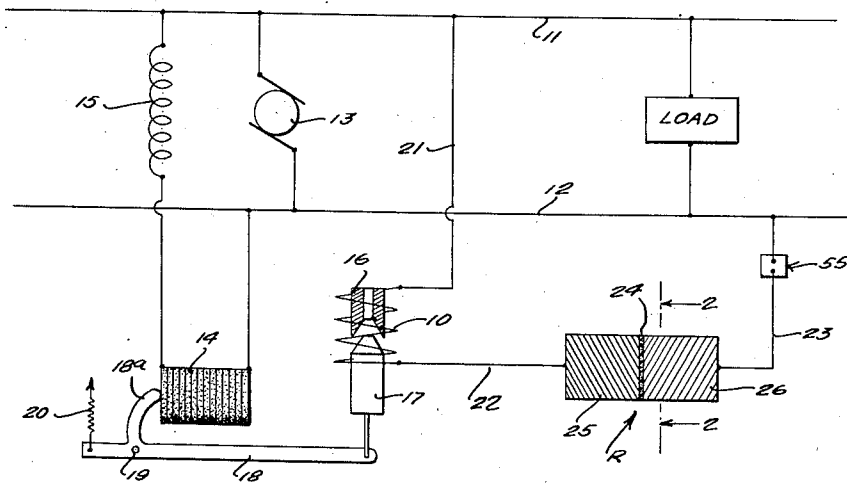


Fig. 2.

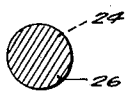


Fig. 3.

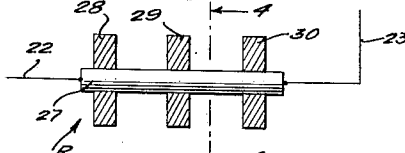


Fig. 4.

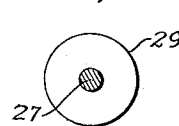


Fig. 6.

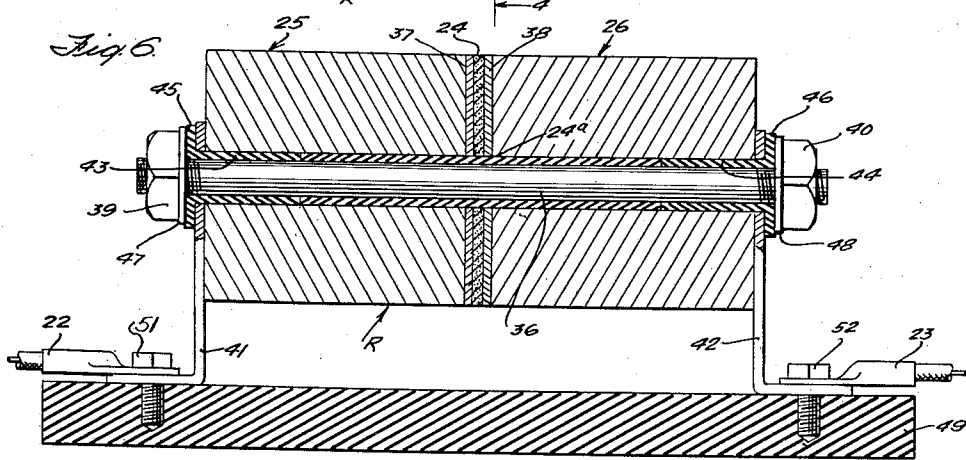
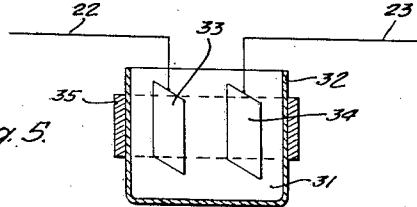


Fig. 5.



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Fig. 7.

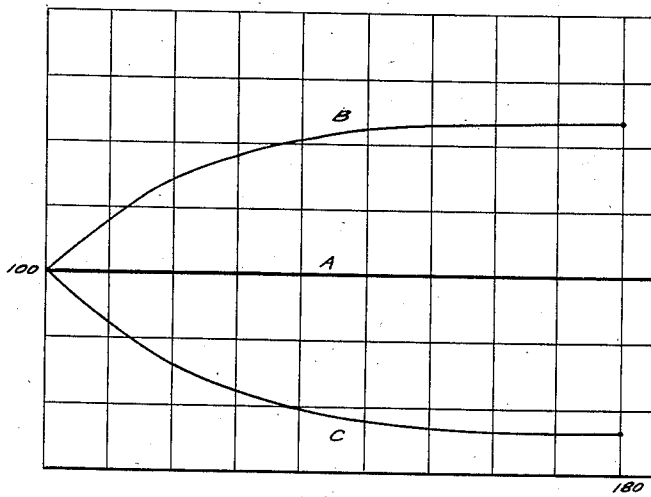


Fig. 8.

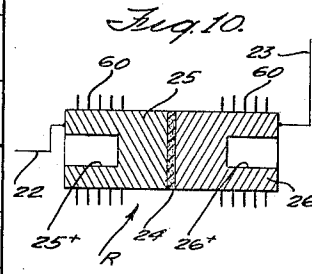
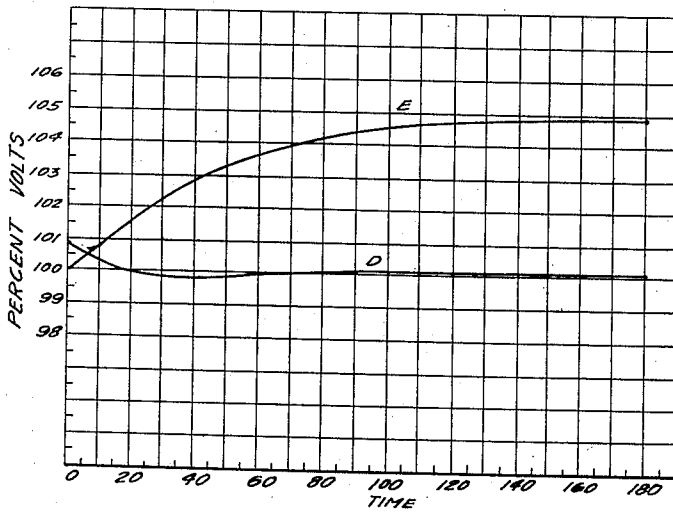


Fig. 11.

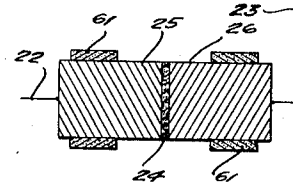
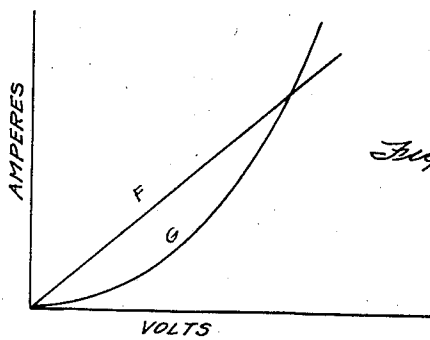


Fig. 9.



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ELECTRIC REGULATION

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Application January 21, 1935, Serial No. 2,707

25 Claims. (Cl. 171-229)

This invention relates to electric regulation.

One of the objects of this invention is to provide a simple, practical and inexpensive regulating system and apparatus that will be of efficient and reliable action and capable of precision and accuracy of regulation throughout the peculiarly varying conditions of practical use, particularly variations in temperature. Another object is to provide a system and apparatus for the regulation of electrical circuits that will be of wide adaptability and use in successfully coping with the heretofore unsurmounted difficulties caused by changes in temperature. Another object is to provide an electromagnetic control apparatus for a system or electrical apparatus that will maintain dependably and efficiently the desired or intended standard of operation or control thereof in spite of changes in resistance of the electromagnetic winding due to temperature changes, and to provide such a control system or apparatus capable of a wide range of use in the electrical arts. Another object is to provide a system or apparatus of the above mentioned character in which the efficiency is vastly improved, energy consumption diminished, and genuine precision of action achieved. Another object is to provide a system or apparatus of the above mentioned character that will be of simple and inexpensive construction, capable of ready and convenient installation, and compact and rugged in construction. Other objects will be in part obvious or in part pointed out hereinafter.

The invention accordingly consists in the features of construction, combination of elements, and arrangements of parts as will be exemplified in the structure to be hereinafter described and the scope of the application of which will be indicated in the following claims.

In the accompanying drawings, in which are shown several of the various possible embodiments of certain mechanical features of my invention,

Fig. 1 is a diagrammatic representation of one form of regulating system and apparatus, part of the latter being shown in cross-section, and Fig. 2 is a transverse sectional view as seen along the line 2-2 of Fig. 1;

Fig. 3 is a vertical sectional view of a modified embodiment of part of the system and apparatus of Fig. 1, and

Fig. 4 is a transverse sectional view as seen along the line 4-4 of Fig. 3;

Fig. 5 is a vertical sectional view of another possible embodiment of part of the system and apparatus of Fig. 1;

Fig. 6 is an enlarged detailed vertical sectional view of part of the system and apparatus of Fig. 1;

Fig. 7 reproduces graphically certain of the actions that take place in my system and apparatus;

Fig. 8 reproduces graphically, for purposes of illustrative comparison, certain results achieved by my system and apparatus on the one hand and by apparatus as heretofore constructed and operated;

Fig. 9 shows graphically certain impedance characteristics of certain impedance materials;

Fig. 10 is a vertical sectional view of part of the apparatus of Fig. 1, illustrating a possible way of achieving or modifying certain characteristics thereof; and

Fig. 11 is a view like that of Fig. 10 showing another illustrative embodiment or arrangement for achieving or modifying certain characteristics.

Similar reference characters refer to similar parts throughout the several views in the drawings.

As conducive to a clearer understanding of certain features of my invention it might at this point be noted that in the electrical arts, particularly in the field of, for example, regulation of electric circuits for constancy of voltage, reliance has to be placed upon an electromagnetic winding in the form of a coil or helix, an electromagnet with an armature controlled thereby, or a solenoid winding with a core controlled thereby; in such an electromagnetic winding, of which examples have just been noted purely by way of illustration, the conductor, usually copper wire, of which the winding is made, is subject to variations in temperature due to electrical heat losses in the resistance of the conductor itself. The electrical energy dissipated in the form of heat in the conductor is proportional to the product of the square of the current by the resistance of the conductor itself. With change in temperature, the resistance of the conductor and hence of the winding also changes. The temperature, and hence the resistance, of the conductor making up the winding is thus subject to relatively great changes, being further affected by such variables and factors as the temperature of the atmosphere, the temperature of the apparatus with which the winding may be closely associated physically, the rate of heat dissipation by the winding, the length of the periods of energization of the winding as compared with the length

of the periods when the winding is de-energized, and other factors.

If therefore the winding is intended to control, through its induced magnetic flux, any related apparatus, mechanisms, circuits, or the like, the production of a critical value of flux must be dependent upon achievement of a fixed or critical value of current through the coil, but due to the variability of the resistance of the winding as above pointed out, the voltage necessary to achieve this given value of current from the winding will necessarily vary with the variations in the resistance.

Let it be assumed, for example, that the winding is to achieve, with related means, constancy of voltage in an electrical circuit; if the winding and its related parts are so constructed as to regulate for constancy of current (to produce the above mentioned flux), the voltage necessary to maintain this constancy of current through the winding varies with the change in resistance of the conductor of the winding, assuming that the winding is bridged directly across the circuit the voltage of which is to be maintained constant. The result is that very substantial departures from the desired value of voltage are caused by the change in the resistance of the winding.

It has heretofore been proposed to counteract these effects by placing in series with the winding a relatively large external resistance of zero temperature coefficient of resistance and such an arrangement has become wide practice; the theory of such practice is that, by thus greatly increasing the total resistance of the winding circuit, the change in resistance that takes place within the winding itself becomes a small enough factor relative to the total circuit resistance to tolerate the nevertheless inescapable fact of change in voltage of regulation. However, such an arrangement does not remedy the difficulty and is moreover of limited scope of application, not to mention its wastefulness of material and electrical energy or low efficiency. Where the energy requirements of the winding or controlling coil are relatively large, the applicability of this prior practice fails unless many disadvantages can still be tolerated.

For example, let it be assumed that the control winding has to be constructed so large that its energy requirement is 100 watts; if the change in resistance of such a winding causes a 15% voltage variation and if it is desired to reduce that variation to a maximum of 5%, it is necessary to have connected in series with the winding an external resistance which is twice that of the winding, the external resistance requiring therefore that an additional 200 watts must be dissipated therein. If the range of change of temperature of the control winding is still greater, with corresponding change in resistance, then ever larger values of external resistance must be used to reduce the ultimate voltage variation. These instances illustrate some of the distinct disadvantages of such prior practice which, in no case, it will be seen, achieve an entire absence of voltage variation. If the winding therefore is employed for regulation of voltage, constancy of voltage cannot be and is not achieved.

One of the dominant aims of this invention is to do away with such disadvantages as have just been noted above and to provide a system and apparatus in which genuine control or regulation may be dependably and inexpensively

achieved, and maintained throughout the widely varying conditions of practical use.

Referring now to Fig. 1 of the drawings, I have there diagrammatically shown an electromagnetic winding 10 of the general character above mentioned; by way of illustration and to clarify a ready understanding of my invention, I have shown the winding 10 as the control or regulating winding in a system or apparatus for achieving constancy of voltage across the circuit 11-12, winding 10 being connected, as more clearly hereinafter described, to be responsive to that function (voltage, in this instance) of the electrical energy in the circuit 11-12 which it is desired to maintain constant.

In so far as certain features of my invention are concerned, the winding 10 may control, affect, or actuate or coact with any desired or suitable parts or apparatus which are, by the winding 10, made to effect a correction of departures from the selected value of the function of the electrical energy that it is desired to maintain constant. For example, the winding 10 may be in the form of a relay for controlling a resistance which in turn is made to affect the voltage across the circuit 11-12; thus, for example, a generator 13 (either alternating current or direct current) may be the source of supply of electrical energy to the circuit 11-12 and the resistance, illustratively in the form of a carbon pile 14, may, under the control of the winding 10, affect the excitation of the field winding 15 of the generator 13, thus to control the voltage of the output of the electrical source 13.

By way of further illustration, the winding 10 may form part of a solenoid having a fixed core 16 and a coaxing movable core 17, these two parts being suitably shaped, as by tapering them as is indicated in Fig. 1, so that, with respect to the mechanical resistance opposing movement of the movable core 17, the winding 10, at a given or intended energization, will hold the core 17 in whatever position it is moved throughout its range of movement. Movable core 17 may be connected to a bell crank lever 18 pivoted at 19, and having its one arm 18a operating upon the free or unanchored end of the carbon pile 14. A spring 20 opposes the pulling effort of the solenoid.

Disregarding resistance changes in the winding 10, increase in voltage across the circuit 11-12 increases the energization of the winding 10 beyond the value corresponding to the voltage desired to be maintained constant across the circuit 11-12, whereupon the pressure on the carbon pile 14 is lessened, its resistance increased, and the resultant decrease in the excitation of the generator 13 restores the voltage to normal. Should the voltage decrease, a reverse action takes place in that the corresponding decreased energization of the winding 10 disturbs the mechanical equilibrium theretofore existing and permits the spring 20 to swing the lever 18 in clockwise direction, thus increasing the pressure on the carbon pile 14 and correspondingly increasing the excitation of the generator 13 to restore its voltage to normal.

As above pointed out, where the winding 10 is to respond to changes in voltage, it is bridged across the circuit the voltage of which is to be affected. Accordingly one terminal of winding 10 is connected by conductor 21 to one side, conductor 11, of the circuit 11-12; the other terminal of winding 10 is connected by conductors 22 75

and 23 to the other side, conductor 12, of this circuit, but through a temperature-change compensating device generally indicated at R.

The device R includes a member 24 having a negative temperature coefficient of resistance and has thermally related to it means giving the part 24 a thermal capacity which is high compared to the thermal capacity of the part 24 itself. The winding 10 may be constructed in any suitable manner; whatever its physical construction, it embodies necessarily the mass of conductor (usually copper) of which it is wound together with such possible related parts as an iron core, parts either of solid dielectric material or of metal between which or upon which the conductor is wound, and like parts, giving the winding an ultimate mass having a certain area of exposed surface or surfaces which can and do function as heat-radiating or heat-dissipating surfaces. Depending upon such factors as these, varying as they do with the design, purpose, power, or physical dimensions of the winding, the winding is found to have a thermal capacity which is, relatively speaking, large, and it is found that the winding has a corresponding characteristic of rate of rise of temperature beginning with the flow therethrough of its rated energizing current and hence also a corresponding characteristic of rate of decrease of temperature when the energizing current is cut off. The relatively large ratio of thermal capacity of the coil to cooling surface area of the coil makes this rate of change of temperature relatively low.

The device R (Fig. 1) embodying a relatively small part 24 (inherently of small thermal capacity) has thermally related to it one or more members, illustratively two in number as shown at 25 and 26 in Fig. 1, of a material like cast iron, steel, brass, or other suitable metal or material, in sufficient volume or mass to give the device R, with respect to the latter's heat-radiating surfaces, a high thermal capacity, and moreover a ratio of thermal capacity to heat-radiating surface of device R that is equal to or commensurate with the ratio of the thermal capacity of the winding 10 to the heat-radiating surface of the winding 10.

By way of illustration the part 24, having a negative temperature coefficient of resistance and made of any suitable material having such a coefficient, such as carbon, carbon compositions, psilomelane, galena, silicon, carbide, zincite, graphite, certain alloys (such as bronze made up of 88% of copper and 12% of tin with a small quantity of phosphorus), may be in the form of a disk interposed between the ends of the parts 25 and 26 which are made up in the form of preferably cylinders made, for example, of cast iron.

The members 25—26 may or may not be included in the circuit of the winding 10 though it is more convenient to include them in that they may thus also serve as the contactors with the disk-like resistance element 24; the cross-section of metal in the members 25—26 is sufficiently large virtually in any case so as not materially to affect the resistance of the circuit or to be materially affected by I^2R losses therein. In any event the resistor 24, of negative temperature coefficient and of small mass and hence of small thermal capacity, is in the circuit of the winding 10 and has its thermal capacity greatly increased by being thermally related to a relatively large mass such as the metal members 25—26. As the resistor 24 heats up, due to the

flow of current therethrough, heat flows from the resistor 24 to the mass 25—26, the total mass of the device R being given such an external or other exposed heat-dissipating surface that the rate at which the temperature of the entire mass of the device R changes with flow of current through the resistor 24 substantially matches or equals the rate of change of temperature of the winding 10. Depending upon the relative temperature coefficients of resistance and upon the relative ohmic resistances of the winding 10 and the resistor 24, the mass of the part or parts 25—26 and the heat-dissipating surfaces thereof may be changed or determined to control the rise or fall of temperature of the resistor 24 with continued flow of current or cessation thereof respectively so that the increment of change of resistance in winding 10 in one direction is exactly counterbalanced by an equal increment of change in resistance in the resistor 24 in the opposite direction.

With this arrangement exact or precise regulation at the intended voltage may be accomplished. The action achieved by the above described interrelation of the thermal capacities of the winding and resistor unit may be better understood if reference is now made to Fig. 7 of the drawings.

In Fig. 7 the curve A represents the voltage of the circuit being regulated over a period of time beginning with the closure of the regulating circuit (with the parts starting at room temperature) and terminating at the end of three hours or so when, under the there existing conditions, steady conditions of ultimate temperature had been achieved. Curve A is substantially a straight line with detectable variations therein of only a small fraction of one per cent. departures from the intended value of voltage to be kept constant. Curve B represents, for the same period of time, the percentage variations of voltage across the coil 10 of Fig. 1, and shows a progressive increase in voltage from substantially zero to about 5%, representing the steady increase in voltage across the coil 10 necessary to maintain the current therein constant against the steadily increasing resistance accompanying the rise in temperature of the winding 10. Curve C represents the percentage decrease in voltage across the resistor 24 of Fig. 1 and it will be seen that curve C is geometrically similar to curve B, both curves clearly showing that for each increment of increase in resistance in the winding 10 there was a corresponding decrement in the resistance of the resistor 24 and since the same current flows through both winding and resistor, the resultant voltage drops always total the same, namely, the voltage of the circuit 11—12. Where one voltage drop (that across the winding 10) increased, the other voltage drop (across the resistor 24) decreased in exactly the same extent.

Should the circuit of coil 10 be interrupted at any time, the rates of heat loss from the thermal masses represented by the winding 10 and by the resistance device R will substantially follow the characteristics of Fig. 7 so that, should the circuit of the winding 10 be restored before it is completely cooled off, as might be the case where winding 10 operates intermittently, the temperatures of the winding 10 and the resistor 24 will have been maintained in their proper relations so that a subsequent closure of the circuit finds the then existing temperature-resistance condition of the winding 10 exactly

compensated for by the then existing temperature-resistance condition of the resistor 24.

The regulation thus achieved will be seen to be virtually 100% perfect inasmuch as curve A is virtually a straight line parallel to the horizontal axis and is devoid of variations or fluctuations beyond a virtually imperceptible or immaterial small fraction of one per cent., even though the temperature of operation varies throughout relatively wide limits. Fig. 8 shows by way of comparison the performance of my system and apparatus as compared with a regulating system and apparatus devoid of the compensating features of construction and action above described; curve D is virtually a reproduction of curve A of Fig. 7 and again shows the high precision at which constancy of voltage is achieved while curve E shows the rate of change and magnitude of change of voltage of regulation, during the period that the regulating coil warms up to operating temperature, even though the control or regulating winding (of curve E) is in series with a resistance having a zero temperature coefficient of the type earlier above described; within practical limits of energy consumption and of magnitude of external resistance, curve E demonstrates how the best performance thus achievable is inherently characterized by a change in standard of voltage regulation that is great as contrasted with a small fraction of one per cent. (curve D) achievable with my system and apparatus.

In Fig. 3 I have illustrated a possible modified form or physical embodiment of the resistance device R, simply to illustrate that the device R may be given other forms than that shown in Fig. 1 and more specifically described later herein in connection with Fig. 6. In Fig. 3 the resistance element (corresponding to the resistor 24 of Fig. 1) may take the form of a rod 27, made of any suitable material as above mentioned in connection with the resistor 24; the rod 27 has associated with it one or more masses of a material preferably metal in order to increase its thermal capacity and by way of illustration I have shown the rod 27 of Fig. 3 surrounded by three annular-like (see also Fig. 4) members 28, 29 and 30, preferably of metal, and strung on to the rod 27 but in close thermal contact therewith. The members 28—29—30 are proportioned as to axial length and radial thickness to give the desired heat-absorbing mass and the desired heat-radiating exposed surfaces, all of course appropriately proportioned with respect to the thermal capacity and exposed heat-dissipating surfaces of the winding 10, as was described in connection with the device R of Fig. 1.

Or, under certain circumstances, the resistor of the device R may take the form of an electrolyte having a suitable temperature coefficient of resistance, preferably negative. The electrolyte might comprise a 5% solution of nitric acid having a temperature coefficient of -0.015 , or it might be a 5% solution of copper sulphate whose temperature coefficient is -0.021 ; these electrolytes are mentioned purely by way of example. In Fig. 5 the electrolyte 31 is contained in any suitable vessel or receptacle 32 and immersed therein are suitable electrodes 33—34 to which the conductors 22 and 23 (see Fig. 1) may be connected in order to relate the resistance device to the winding 10. The material of which the receptacle 32 is made is preferably a material of good heat conductivity

and, with the body of the electrolyte itself and its own thermal capacity, the receptacle is proportioned so that the resultant heat-radiating surface and thermal capacity are appropriate to cause its rate of rise or fall in temperature to match the rate of rise or fall in temperature of the winding 10. If desired or if necessary the thermal capacity may be increased by increasing the mass or volume of the material of which the receptacle 32 is made or by relating to the receptacle 32 one or more members or parts (broadly similar to the parts 25—26 of Fig. 1 or to the parts 28—29—30 of Fig. 3) of metal or other suitable material, such as the part 35 of Fig. 5. For example, if the receptacle 32 is of a circular horizontal cross-section, the part 35 may be in the form of a collar or ring extending about the receptacle 32 and brought into intimate thermal contact with the latter and hence also with the electrolyte 31.

I have above made brief reference to Fig. 6 in which is shown in vertical cross-section, on an enlarged scale, the resistance device R of Figs. 1 and 2, with its details. Turning, therefore, to Fig. 6, the disk or ring-shaped resistor 24 is shown interposed between the ends of the metal cylinders 25—26, while the parts 25 and 26 respectively are suitably bored out (as is also the resistor 24, as at 24^a) to permit the passage through these three parts of a clamping bolt 36 to hold the three parts 25—24—26 in secure assembled relation.

Preferably washers or gaskets 37—38 of a suitable relatively soft metal, such as lead for example, are interposed between the contacting faces of the three parts in order to insure uniform distribution of the clamping pressure throughout the affected portions of the resistor 24; this feature is of particular advantage where the resistor 24 is made up of a carbon or graphite composition or of a composition described in detail hereinafter. Also the lead washers 37—38 insure a good electrical surface contact with the resistor 24 in that they yield and adjust themselves to unintentional or unavoidable irregularities or variations in the surface of the resistor 24 itself; and further, the washers 37—38 provide good thermal contact between the resistor 24 and the parts 25—26.

The clamping bolt 36 is threaded at one end or at its two ends to receive the clamping heads or nuts 39—40 in order that the appropriate clamping pressure may be applied and maintained. But the clamping bolt 36 also and conveniently serves to mechanically hold and thus electrically connect to the device R two supporting brackets 41—42 of metal, being suitably apertured to let the clamping rod 36 pass there-through. The parts are so related and shaped that the clamping rod 36 is insulated from the metal parts 25—26 and also from the connecting and supporting brackets 41—42; for this purpose a tube-like insulating bushing 44, provided with insulating washers or flanges 45—46, extends about the bolt 36 and through the apertures in the bracket 41 and cylinder 25 on the one hand and the apertures through the bracket 42 and the cylinder 26 on the other hand. Metallic washers 47 and 48 rest against the insulating parts 45—46 and underneath the nuts 39—40 and thus the parts 42, 26, 38, 24, 37, 25 and 41 are dependably held together mechanically and reliably held in electrical interconnection to form a circuit therethrough which may be traced in the order in which these parts have

just been identified. Also a good thermal contact is assured between adjacent or engaging parts. By means of the brackets 41-42, the device R may be mounted on a suitable base 49 of insulating material (Fig. 6) as by screws or bolts 51-52 which may be and conveniently are utilized also to bind or clamp the conductors 22 and 23 (see Figs. 1 and 6) of the circuit in which the device R is to be included.

I have above mentioned, by way of illustration, certain specific examples of materials which may be employed in my system and apparatus and which have a suitable negative temperature coefficient of resistance. Now in accordance with certain other features of my invention, I may employ for the material of the resistance medium, such as the resistor 24 or 27 of Figs. 1 and 3 respectively, material having the characteristic of changing its ohmic resistance with change in voltage applied to the resistance material itself.

Such materials which substantially depart from Ohm's law in that the current flowing in the circuit is not necessarily proportional to the voltage impressed are known as non-linear impedances, and may take the form of inductances with iron cores, thermionic vacuum tube conductors, gaseous discharge devices such as neon lamps or helium glow lamps, certain electrolytic conductors, and many other devices. Some devices are pure resistance devices and follow Ohm's law for direct current, such as an iron-cored inductance, while on alternating current, the impedance of the device or its resistance to current flow, is dependent upon the impressed voltage and other factors, such as the frequency of alternating voltage. Other materials have a practically instantaneous response to voltage variations, so that the characteristics do not depend upon its immediately previous history, and therefore at any given instant the amount of current flowing through the material depends only upon the voltage impressed at that instant and not upon the current flowing the previous instant.

A material may be selected so that as the voltage impressed on the material increases, the current may increase at a greater rate than would be the case if current were always proportional to the voltage impressed. Thus, in a pure resistance with a linear impedance characteristic, the current will be proportional to the impressed voltage as shown by the curve F in Figure 9.

With a non-linear impedance material used for the resistance unit, the current may not be proportional to the voltage, as shown in curve "G" of Figure 9. In the latter, the current of curve G increases much more rapidly with voltage than does the current of curve F. Thus, if in a regulating system a definite current change must be made in the current of energization of winding 10 (Figure 1) in order to overcome mechanical friction and magnetic hysteresis to achieve a desired change, the change in voltage for a pure linear impedance as exemplified in curve F will require the same percent variation in regulated voltage to achieve the required current change as is the magnitude of the current change in percent of total current flowing in winding 10. However, if a non-linear impedance material is used as the resistance element in the coil circuit of winding 10, then it is readily apparent that a small voltage variation will result in a relatively large change in current in winding 10 in its attendant non-linear resistance unit.

Therefore, to obtain a required current change

in winding 10, the change in regulated voltage will be much less if a material of a non-linear impedance characteristic such as shown in curve G is used rather than a linear impedance as in curve F.

In alternating current circuits, such an effect is obtainable very readily by placing an iron-cored inductance in series with the winding 10, so proportioning the core in the inductance coils that the iron is near or beyond its saturation value at the voltage at which the system is to regulate.

In both alternating and direct current circuits, materials which have a practically instantaneous response to voltage variations are of advantage due to their independence of the frequency of the system voltage, whether alternating or direct current.

One such material is commercially known as "Thyrite", and is described in U. S. Patent No. 1,822,742 issued on September 8, 1931. This material, described in the "General Electric Review" of February, 1930, has mechanical characteristics somewhat similar to those of dry-process porcelain and has the characteristic that its conductivity varies with the potential. For example, the ohmic resistance is equal to a constant (which depends upon the physical dimensions of the material to be employed) divided by the current to the exponent α , as set forth in the above-mentioned publication. To illustrate the action of this material, it might be noted that its above-mentioned properties are of such a character that doubling the voltage results in a flow of current therethrough the magnitude of which is on the order of twelve times the magnitude of the current flowing before the voltage was doubled. Thus, the resistor 24 of Figures 1 and 6, for example, may be in the form of a disk of "Thyrite", illustratively a disk or annulus of about three inches in diameter and about one-eighth of an inch in thickness. This material, moreover, also has a negative temperature coefficient of resistance in that its resistance decreases with increase in temperature.

In addition to the advantages resulting from the use of a resistor with a negative temperature coefficient of resistance, a resistor made up of this material such as "Thyrite", achieves many marked advantages. Illustratively let it be assumed that the winding 10 has the following characteristics, namely, a resistance on the order of 100 ohms, an operating voltage on the order of 50 volts, and an operating current or a critical current of energization of 0.5 ampere; let it be assumed, also, that, in accordance with the past practice as hereinabove earlier mentioned, there is included in the circuit of this winding an external resistor of 200 ohms, so that at 0.5 ampere, the voltage drop across the resistance is 100 volts. A variation of 3% in the current of energization due perhaps to any condition of electromechanical unbalance in a regulating or relay system would result in a variation of 1.5 volts across the winding and of 3.0 volts across the resistance making a total voltage variation to which the system and apparatus is subjected of 4.5 volts.

If, however, instead of using such a resistance in accordance with prior practice, I use a resistor of "Thyrite" in circuit with the above-assumed winding such that the above-mentioned 3% voltage variation (increase in voltage drop across the winding 10 due to the increase in current of energization) is effective, due to the above-

described characteristic of the material, to produce a voltage drop across the resistance of only 0.25 volt, then the total voltage variation of the system, instead of being 4.5 volts, becomes the sum of 1.5 volts and 0.25 volt and hence 1.75 volts, resulting in a total voltage variation of only about 1.2% of the total voltage of 150 volts of the circuits 11—12. Thus the performance of the system and apparatus is vastly improved with respect to the voltage sensitivity of the system including winding 10 and resistor R, a relatively small voltage variation resulting in a large change in current of energization.

The resistance material, having the above-mentioned novel characteristics I may employ in various ways; for example, I may embody it in the form in which the resistors of Figs. 1, 3 and 6 are embodied, relating it to appropriate masses of appropriate thermal capacities and heat-radiating surfaces or I may let these resistances of Figs. 1, 3 and 6 take the form or forms above described, including the form in Fig. 5, relying upon the negative resistance coefficients of temperature and include in the circuit of the corresponding resistor device R and winding 10 an additional resistor made up of a non-linear impedance characteristic; in Fig. 1 I have diagrammatically indicated at 55 how the resistor of this material may be thus included in the system and apparatus. In such case I am enabled to reduce the size and thermal capacity of the resistor R due to the coacting effect of the resistor 55. In such case also I may dispense in the resistor device R with a resistor having a negative temperature coefficient of resistance and use a resistance of zero temperature coefficient, retaining only the non-linear impedance characteristics of resistance, although commonly a resistance material of non-linear impedance characteristic has also a negative temperature coefficient of resistance.

The ratio of thermal capacity to heat-radiating surface of the device R, to meet any particular or desirable condition of operation, may, moreover, be achieved, or varied as may be desired, in any suitable or desirable way; for example, and again considering illustratively the embodiment shown in Figure 1 and more in detail in Figure 6, if it is desired to obtain a more rapid rise in temperature in the device R and to obtain a higher ultimate rise in temperature, the parts 25 and 26, illustratively cylindrical as above noted, may be given correspondingly smaller dimensions, as by reducing the axial length, correspondingly to achieve a change in thermal capacity and in cooling surface. For example, and purely by way of illustration, let it be assumed, in Figure 1 or 6, that the disk-like resistance element 24 is made of the above-mentioned "Thyrite" material and is approximately one-eighth of an inch thick and three inches in diameter; let it further be assumed that the characteristics of coil 10 are such that there is about a 40° C. rise in temperature with an increase of about 15% in resistance of the copper coil. By giving the solid cylindrical members 25 and 26, illustratively made of iron or steel, a diameter of 3" and an axial dimension of 3" each, the ratio of thermal capacity of the device R to its heat-radiating surface becomes such that the resistance element 24 is subjected to a rise in temperature of about 80° C., just about appropriate to achieve the earlier above-described compensation for the temperature rises

or changes in the regulator coil 10 and its associated parts.

To illustrate further, let it be assumed, however, that the regulator coil 10 and its associated parts have such a ratio of thermal capacity to heat-radiating surface that the rise in temperature thereof is on the order of 55° C. to 60° C. with a resultant increase in resistance, due to this temperature rise, that may be 20% or more. To achieve the desired compensation in the device R, a greater rise in temperature therein is now necessary and hence a different ratio of thermal capacity to heat-radiating surface. Appropriate compensation is achieved by decreasing the axial length of the parts 25 and 26 and it so happens that if they are now made about 2" in axial length instead of 3" as above assumed, an appropriate ratio results to give exactly the compensation desired, as earlier above described in detail; in such case, the rise in temperature of the disk-like resistance element 24 is approximately 115° C. to 120° C.

These two illustrations will suffice to illustrate in detail such changes, based upon two illustrative but different practical requirements, that may be made to obtain a ratio of thermal capacity to heat-radiating surface of the device R that substantially matches the ratio of thermal capacity to heat-radiating surface of the coil and its associated parts.

However, other means may be employed to obtain the desired ratio. For example, and referring now to Figure 10, and assuming that the coil 10 and its related parts require, in the device R, a lower ratio of thermal capacity to heat-radiating surface, I may provide the parts 25 and 26, or either of them, with, for example, heat-radiating fins 60. Or the parts 25 and 26 may be hollowed out or counterbored, as at 25' and 26'. Or, as will now be clear, I may select any appropriate material of which to make the parts 25 and 26, selecting the material in accordance with itself, and appropriately dimensioning the part or parts of such material; for example, iron has a specific heat of 0.1138, aluminum 0.2143, lead 0.0314, and so on.

I may achieve the desired ratio of thermal capacity to heat-radiating surface of the illustrative parts 25 and 26, or either of them, by dimensioning the parts to have the desired thermal capacity and then diminish the existing heat-radiating surface thereof as by covering an appropriate portion of the otherwise available heat-radiating surface with a good non-conductor of heat, such as asbestos in appropriate thickness. In Figure 11 I have shown the parts 25 and 26 provided with a wrapping, of appropriate axial extent, made of such heat-resisting or insulating material, as is indicated at 61.

And, as will now be clear, the desired ratio may be achieved, changed, or altered, with respect to the device R of Figures 3 and 5, in manners and by means such as those illustratively just described.

Thus, it will be seen that there has been provided in this invention an apparatus in which the objects above-mentioned, together with many thoroughly practical advantages, are successfully achieved. It will be seen that the invention is of a thoroughly practical character, and is in action dependably precise, and is, moreover, well adapted to meet the varying conditions met with in practice.

As many possible embodiments may be made of the above invention and as many changes

might be made in the embodiment above set forth, it is to be understood that all matter hereinbefore set forth, or shown in the accompanying drawings, is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. In a system of electric regulation, in combination, a circuit having therein electromagnetic means for controlling a regulating means, said electromagnetic means having a certain ratio of thermal capacity to heat-radiating surface thereof and having a positive temperature coefficient of resistance, and means in circuit with said electromagnetic means and having a negative temperature coefficient of resistance and substantially the same ratio of thermal capacity to heat-radiating surface as said electromagnetic means.

2. In a system of electric regulation, in combination, a circuit having therein a regulating coil of given ratio of thermal capacity to heat-radiating surface and having the characteristic of change in resistance with change in temperature thereof due to I^2R loss therein, and means for maintaining the current through said coil substantially constant in spite of change in resistance thereof comprising a resistance element having the characteristic of changing its resistance as its temperature increases due to I^2R loss therein in a direction opposite to the direction in which the resistance of said coil changes, and means thermally related to said resistance element to give it a thermal capacity and heat-radiating surface such that the ratio therebetween is substantially the same as said first-mentioned ratio.

3. In a system of electric regulation, in combination, a circuit having therein a regulating coil whose impedance changes with change in operating temperature and having serially related thereto a compensating impedance means, the ratio of thermal capacity to heat-radiating surface of said coil and of said impedance means being substantially the same.

4. In a system of electric regulation, in combination, a circuit having therein a translating device in which is included conductive means whose impedance changes with change in operating temperature, and means for maintaining the current in said circuit substantially constant as against the change in impedance of said conductive means comprising conductive means connected serially with said first-mentioned conductive means and having the characteristic of changing its impedance with change in operating temperature but in a direction opposite to the direction in which the impedance of said first-mentioned conductive means changes, and means thermally related to said second-mentioned conductive means to give it a thermal capacity and heat-radiating surface such that the ratio therebetween is substantially the same as the ratio being the thermal capacity and heat-radiating surface of said translating device.

5. In a system of electric regulation, in combination, a circuit having therein a translating device in which is included conductive means whose impedance changes with change in operating temperature, and means for maintaining the current in said circuit substantially constant as against the change in impedance of said conductive means comprising conductive means connected serially with said first-mentioned conductive means and having the characteristic of changing its impedance with change in operating

temperature but in a direction opposite to the direction in which the impedance of said first-mentioned conductive means changes, said translating device and said second-mentioned conductive means having, with respect to the atmosphere in which they operate, substantially identical rates of heat dissipation.

6. In a system of electric regulation, in combination, a circuit having connected thereacross voltage-responsive regulating means whose impedance changes with change in operating temperature, and means for preventing such change in impedance from materially affecting the standard of voltage regulated by said regulating means comprising compensating impedance means electrically related to said regulating means, the ratio of thermal capacity to heat-radiating surface of said regulating means and of said compensating impedance means being substantially the same.

7. In a system of electrical regulation, in combination, a circuit having therein a translating device which has a certain thermal capacity and a certain heat-radiating surface and having the characteristic of changing its impedance with changes in operating temperature, and compensating impedance means electrically related thereto and comprising an impedance device having the characteristic of changing its impedance in the opposite direction with change in operating temperature but physically having a ratio of thermal capacity to heat-radiating surface different from the ratio of the thermal capacity to heat-radiating surface of said translating device and means physically related to said impedance device to give it an effective ratio of thermal capacity to heat-radiating surface substantially equal to the ratio of thermal capacity to heat-radiating surface of said translating device.

8. A system as claimed in claim 7 in which the impedance device is in the form of a disk-like member and in which the means physically related to the impedance device comprises a metallic means of appropriate mass and heat-radiating surface.

9. A system as claimed in claim 7 in which the impedance device is in the form of a disk-like member and in which the means physically related to the impedance device comprises two metallic means, each adjacent to a face of said disk-like member and being together of the desired mass and heat-radiating surface.

10. A system as claimed in claim 7 in which the impedance device is in the form of a disk-like member and in which the means physically related to the impedance device comprises two metallic means and means for holding them and said disk-like member together with the latter between them.

11. A system as claimed in claim 7 in which the impedance device is in the form of a disk-like member and in which the means physically related to the impedance device comprises two metallic members between which said disk-like member is positioned, and means extending through all three and insulated therefrom for holding them in cooperative physical and thermal relation.

12. A system as claimed in claim 7 in which the means thermally related to the impedance device comprises a hollow member.

13. A system as claimed in claim 7 in which the means thermally related to the impedance device comprises a member of appropriate

thermal capacity and having means for reducing its heat-radiating surface to the desired extent comprising means of suitable resistance to conducting heat covering a desired portion of the heat-radiating surface.

14. A system as claimed in claim 7 in which the impedance device comprises a material having also the characteristic of changing its resistance at a greater rate than but inversely to the rate of change of voltage impressed thereacross.

15. A system as claimed in claim 7 in which the impedance device is in the form of a disk-like member and in which the means physically related to the impedance device comprises two metallic means, each adjacent to a face of said disk-like member and being together of the desired mass and heat-radiating surface, and in which there is interposed between each of the two metallic means and the disk-like member means of good thermal conductivity for insuring good thermal interrelation between the member and said two metallic means.

16. In a system of electric regulation having a work circuit that has an auxiliary regulating circuit connected thereto with electro-responsive regulating means in said regulating circuit, the latter having the characteristic of changing its impedance with changes in operating temperature, the combination therewith of an impedance device in series with said electro-responsive means and having the characteristic of changing its impedance so that the current flow there-through is substantially a logarithmic function of the voltage, the ratio of thermal capacity to heat-radiating surface of said regulating means and of said impedance device being substantially the same.

17. In a system of electric regulation, in combination, a circuit having therein an electrical unit whose impedance changes with change in operating temperature and having serially related thereto compensating impedance means, the ratio of thermal capacity to heat-radiating surface of said unit and of said impedance means being substantially the same.

18. In an electric circuit, in combination, an electrical unit whose impedance changes with changes in operating temperature, and a compensating impedance means, the ratio of the thermal capacity to the ability to dissipate heat to the surrounding medium of said unit and of said impedance means being substantially the same.

19. An electrical circuit which includes a plurality of electrical units one of which is a compensating impedance means whose impedance changes with a change in operating temperature and whose heat-retaining, heat-absorbing and heat-dissipating characteristics are such that with a given variable voltage impressed upon the circuit the temperature of said impedance means will at all times be the same as the temperature of another unit in the circuit.

20. In an electric circuit, an electrical unit having impedance which changes as the operating temperature changes and including portions having heat-generating, heat-accumulating and heat-dissipating characteristics, and a compensating impedance unit having impedance which changes as the operating temperature changes including portions having heat-generating, heat-accumulating and heat-dissipating characteristics, said characteristics of said units being substantially similar.

21. A circuit as claimed in claim 20 in which the compensating impedance unit has two substantially cylindrical metallic blocks in spaced alignment and a substantially disc-shaped resistance element between the adjacent ends of said blocks.

22. A circuit as claimed in claim 20 in which the compensating impedance unit includes a rod-like resistance element and washer-like metallic members fitted upon said rod.

23. A circuit as claimed in claim 20 wherein the compensating impedance unit includes a substantially cylindrical portion and washer-like metallic elements mounted upon said substantially cylindrical portion.

24. A circuit as claimed in claim 20 wherein the compensating impedance unit includes a heat-insulating covering which may be adjusted so as to control the heat-dissipating characteristics of the unit.

25. A circuit as claimed in claim 20 in which the compensating impedance unit includes two bracket members adapted to act as mountings for the units and for wire terminals, two substantially cylindrical metallic elements mounted between said brackets in substantial alignment, a substantially cylindrical resistance element mounted between the adjacent ends of said substantially cylindrical metallic elements, bolt and nut structure holding said elements and said rod elements in place.

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