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ELECTRICAL REGULATOR

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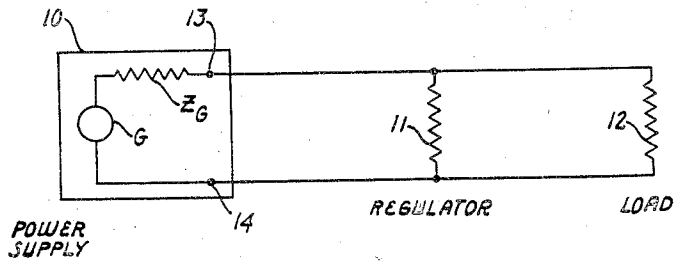


FIG. 1.

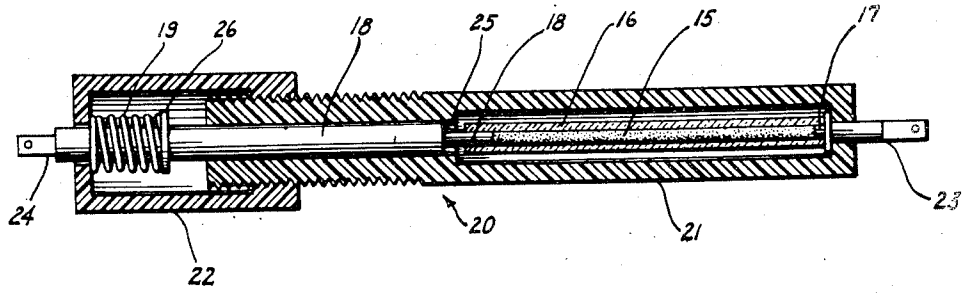


FIG. 2.

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ELECTRICAL REGULATOR

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The present invention relates broadly to voltage regulators and, more particularly, to passive resistive elements which exhibit a pronounced non-linear relationship between the voltage applied across them and the current flowing through them.

It is well known that in electrical systems which comprise a generator, a power supply, and a load suitably coupled thereto, it is often essential to maintain a constant voltage across the load in the face of varying values of power supply output voltage and load current.

The relation between the load voltage under these varying conditions and the load voltage under predetermined normal conditions is termed "regulation," the regulation being said to be "good" when changing conditions produce little or no change in load voltage and "poor" when the opposite is true. It is in this sense that the above terms are used in the subsequent discussion.

When the inherent regulation of an electrical system of the type hereinbefore described is poor, recourse is often had to some type of voltage regulating device which is ordinarily connected intermediate the power supply and the load, for the purpose of improving this regulation.

Such a device may be a so-called non-linear resistor which is characterized in that, over a certain range of values of current flowing therethrough, the voltage across its terminals remains substantially constant. The manner in which such a resistor maintains the load voltage constant is described in more detail hereinafter.

This type of voltage regulating resistor has, in the past, usually taken the form of a carbon-pile regulator which consisted of a stack of contacting carbon disks maintained under pressure. While satisfactory for some applications, this carbon-pile regulator suffered from a number of serious defects. For example, it was unstable inasmuch as its regulating voltage was subject to unpredictable fluctuations. It was also practically useless at high voltages since it was subject to sparking at the junctions between adjacent disks with consequent deterioration of the pile.

On the other hand, a voltage regulating resistor constructed in accordance with my invention is comprised, in general terms, of a single compact column of silicon carbide granules arranged within that column in a manner hereinafter described. The basic features of composition, construction, and of the conduction process which characterize my novel device combine to

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free it of the defects hereinbefore described. In addition, its regulating voltage is readily adjustable and its characteristics capable of complete design.

It is, accordingly, a primary object of my invention to provide a novel voltage regulating resistor.

It is another object of my invention to provide a voltage regulating resistor having readily adjustable regulating voltage.

Still another object of my invention resides in the provision of a voltage regulator which is stable over the operating range for which it is designed.

A still further object of my invention resides in the provision of a voltage regulator which is of simple and sturdy construction.

These and other objects of my invention will become more readily apparent from a consideration of the following discussion in conjunction with the accompanying drawings where

Figure 1 is a schematic representation of an electrical system which comprises a voltage regulator and which will be used to illustrate some of the general properties associated therewith; and

Figure 2 is a representation of a voltage regulating resistor embodying my invention.

As has been briefly pointed out in the preceding discussion, voltage regulators are usually inserted intermediate a power supply and its load. This is schematically illustrated in Figure 1 to which more detailed reference may now be had. In this figure, there is shown a power supply 10, a voltage regulator 11 of the non-linear resistive type here under discussion, and a load 12, all connected in circuit relation. It will be understood that while power supply 10 and load 12 may assume any desired form, they are shown in Figure 1 in their conventional schematic representation, power supply 10 taking the form of a simple voltage generator G in series with an internal impedance Z_G, the output voltage thereof being developed across terminals 13 and 14 and being equal to the voltage generated by generator G less the voltage drop across internal impedance Z_G due to the current flowing therethrough. Load 12 is represented schematically by an impedance connected to the output terminals of the power supply. The regulator 11 is represented as an impedance connected in shunt with the load impedance. The operation of such a system is so well known that a brief recapitulation here will suffice. The load voltage—which it is desired to maintain constant—will be equal

to the voltage across terminals 13 and 14 and thus equal to the voltage generated by generator G less the voltage drop due to current flowing through internal impedance Z_G. The regulator, being in parallel with the load, will, of course, have the same voltage applied to its terminals. Current will flow through the load and through the regulating resistor, the proportion of the current flowing through each being inversely related to their relative impedance values. An increase in generated voltage above its desired value, due to any cause, will result in an increase in the terminal voltage of the power supply and thereby in the voltage across the load and regulator impedances 12 and 11. If the voltage regulator 11 is operating properly, its effective impedance will tend to decrease in response to the increase in voltage thereacross, thereby drawing increased current from the power supply. This in turn increases the voltage drop across the internal impedance Z_G of the supply, thus lowering its terminal voltage until the desired condition of supply and load voltage has been reestablished. The converse phenomenon of course takes place if the generated voltage should decrease. Should the load current, on the other hand, increase (due to a decrease in the value of the load impedance), this would cause increased current drain from the power supply, with attendant increased voltage drop across its internal impedance and lowering of the terminal and the load voltage. This lowering of voltage would also be sensed by the regulator which would again react by increasing its effective impedance, thereby reducing its own current drain on the power supply and compensating for the increased current drain due to the load until the terminal voltage of the supply and, simultaneously, the load voltage are restored to substantially their desired value. Here again a similar reasoning process will explain the converse behavior.

Summarizing then, changes in voltage across a regulator of the type under discussion produce non-linearly related changes of current therethrough in the region in which it provides regulation. In fact, in that region, at any rate, a small increase in voltage produces a relatively large increase in current, while a small decrease in voltage produces a disproportionately large decrease in current. This characteristic is used to impart voltage regulation to an electrical system in the manner hereinbefore outlined.

A regulator which operates in the manner hereinbefore described is illustrated, partly in cross-section, in Figure 2, to which more detailed reference is now made. Such a regulator comprises, in general terms, a column of silicon carbide granules collectively designated by reference numeral 15, the arrangement of these granules in the column being discussed in more detail hereinafter. In its preferred form this column is cylindrical in shape and is enclosed in a closely fitting cylindrical container 16 constructed of some suitable heat-transmissive material such as glass. A solid electrically conductive plug 17 closes one end of the container 16 while pressure is applied to the silicon carbide column, at the other end thereof, by means of a plunger 18 backed by a spring 19. A rigid insulating cylinder 20 may be provided to enclose the entire structure and to provide support for plug 17 at one end and for pressure spring 19 at the other. This cylinder is preferably constructed of two portions 21 and 22 in threaded engagement with each other, this arrangement serving the double purpose of permitting easy assembly of the device and of providing a ready adjustment of the tension of pressure spring 19, the latter being accomplished by varying the degree of engagement of the two sections. Both the plunger 18 and plug 17 may be carried through the end walls of the insulating cylinder and terminated in some suitable terminal arrangement such as lugs 23 and 24 for connection to associated circuit elements. It will be apparent that several features of primarily mechanical significance are also found in the preferred embodiment. For example, the conductive plunger is provided with a shoulder 25 which prevents the end of the plunger from being inserted overly far into container 16. A spring retaining shoulder 26 is also mounted on plunger 18 for obvious reasons. The inside diameter of insulating cylinder 20 is preferably considerably larger than would be required to contain the silicon carbide column and its immediate container 16. This makes it unnecessary to maintain very close tolerances of either the outside of container 16 or the inside of insulating cylinder envelope 20. If this latter tightly surrounded the former, unnecessarily close tolerances would, on the other hand, have to be maintained therebetween, in order to prevent fracture of container 16.

While these several features are principally matters of mechanical and manufacturing convenience and, consequently, do not constitute essential characteristics of my invention, there are a number of others which have a pronounced effect upon the performance of this regulator in accordance with my invention. It is toward these significant features that the immediately subsequent discussion is specifically directed.

To begin with, the silicon carbide granules are placed in container 16 locsely, that is, preferably, without an intervening binding material. In addition to that, they are "aligned." By "aligned" it is meant that they are placed in such relative positions as to occupy the least practicable volume for a given weight. This may be accomplished, for example, if the filling of the envelope is carried out while a strong axial electric field is being applied to the envelope and its contents. Such a field will cause the granules—which may be regarded as roughly ellipsoidal in overall appearance and each having several pointed protuberances—to occupy positions which, on the average, bring the orientation of their longitudinal axes into coincidence with the field direction and therefore also with the longitudinal axis of cylindrical container 16. It should be pointed out, in this connection, that the shape of these granules is, ordinarily, highly irregular. However to the naked eye and under low power magnification, they appear as amorphous bodies of the roughly ellipsoidal form hereinbefore described, which are provided with a few pointed protuberances. Since this macroscopic delineation is sufficient to clarify the various features of the invention, the physical description of the granules will be confined thereto. While the basic phenomena of conduction which underlie the principles of operation of such a voltage regulator are not fully understood, it is believed that this orientation of the particles results in statistically bringing the points of the protuberances of one into contact with the surface of the adjacent ones, thus establishing an apparently highly desirable form of point-to-surface contact. When the silicon carbide granules are thus aligned, the regulator exhibits considerably improved regulation in the sense that there is con-

siderably less change in voltage across it for a given change in current through it, within the range of application of the regulator. In addition, this alignment of the granules succeeds in substantially reducing the tendency of a regulator constructed in accordance with my invention to exhibit voltage-current hysteresis, this being a phenomenon characterized in that the magnitude of the current resulting from increasing the voltage to a predetermined value is different from the magnitude of the current resulting from decreasing the voltage to the same value.

It is clear that such a phenomenon, which, in effect, makes the regulating characteristic dependent upon the past history of the regulator, may be highly undesirable in many applications, and that its elimination, by virtue of the granule alignment hereinbefore described, constitutes an important feature of my invention. It is apparent that alignment within the meaning of the term as hereinbefore defined may be obtained by other means than by application of the aforementioned electric field. For example, vibration applied to container 16 may result in the silicon carbide granules settling into the desired pattern, as well as a combination of vibration and application of the electric field. Thus, only the aligned relationship of the granules, as opposed to the method by which this alignment is attained, is an essential feature of my invention.

Attention is particularly directed to the fact that the nature of the container which encloses the silicon carbide granules plays a significant role in the performance of the regulator, inasmuch as its proper choice also tends to reduce the hysteresis effect hereinbefore described. This is due to the fact that, if the silicon carbide is enclosed in a container made of heat insulating material, then the temperature at the previously described point-to-surface contacts between the individual granules becomes a function of the previous history of the regulator. Since this temperature appears to have considerable influence on the conductivity, the latter will also be affected and voltage-current hysteresis result. On the other hand, the provision of a heat transmissive container facilitates the dissipation of heat from these contacts and renders the conductivity of the regulator more nearly independent of its past history. It is on the basis of these considerations that the preferred embodiment, as hereinbefore indicated, comprises a container made of a suitable heat transmissive material.

Although silicon carbide granules tend to take the form of somewhat oblong particles, their size may be made to vary over a considerable range. This size has an important, though indirect, bearing on the regulating characteristics of my novel regulator. I have found that the regulating voltage is directly proportional to the number of grains per unit height of the column, and hence indirectly proportional to grain size. Thus it would appear that decreasing the granule size would result in increasing the regulating voltage provided the column height is held constant, and this assertion is borne out by experimental evidence.

The current through the voltage regulator, on the other hand, is roughly proportional to the number of granules per unit of cross-sectional area. Thus the conductivity of the regulator decreases approximately with the square of the narrow dimension of the granules. From the above, it is clear that it is a simple matter to

design a voltage regulator in accordance with my invention for any specific application.

As has been cursorily pointed out hereinbefore, the silicon carbide column is preferably maintained under pressure. This may be accomplished in any desired manner, as for example, by means of the arrangement illustrated in and discussed in connection with Figure 2, where a spring-loaded plunger applied a compressional force of readily adjustable magnitude. This application of pressure may be made to serve an important purpose in connection with my novel regulator in that it may, within limits, control the regulating voltage of the regulator. It will be understood that this regulating voltage is primarily a function of the physical dimensions of the silicon carbide column, particularly when considered with reference to the size of the individual granules in the manner hereinbefore described. However, by the application of pressure it is possible to change this regulating voltage to some extent. In general, increased pressure causes lowering of the regulating voltage, it being understood that it is desirable to maintain some minimum pressure on the column at all times in order to insure satisfactory contact between individual granules.

Finally, mention should be made of a feature which has not been previously treated because it is inherent in the operation of my novel type of voltage regulator as described in connection with Figure 1. Reference is had to the fact that some current continuously flows through the regulator regardless of whether the load is open circuited or has some finite value of impedance. This current, termed "stand-by" current, may constitute a substantial fraction of the total current drawn from the power supply, and it inevitably increases, sometimes prohibitively, the current requirements of such a supply. It is therefore highly desirable to maintain this stand-by current at its minimum permissible value for any given value of desired regulating voltage. Fortunately, this is inherently achieved in the preferred embodiment of my invention. Specifically, it is the appropriate application of pressure to the silicon carbide column as hereinbefore described, which, simultaneously with its other effects, results in keeping the value of the stand-by current at a virtual minimum for any particular set of operating conditions.

Although the invention has been described with reference to a single preferred embodiment, its principles have been set forth in sufficient detail to enable those skilled in the art to design and construct other useful apparatus embodying these principles and adapted for other particular applications. Accordingly, I desire my inventive concept to be limited only by the scope of the appended claims.

I claim:

1. A voltage regulating circuit element comprising: a compact column of silicon carbide granules of roughly ellipsoidal form, the longitudinal axis of each of said granules being disposed in substantial alignment with the longitudinal axis of said column, and means for applying a compressional force to said column.

2. A voltage regulating element comprising: a compact column of aligned silicon carbide granules and a pair of electrically conductive connectors, one of said connectors contacting one end of said column and the other of said connectors contacting the other end of said column.

3. A voltage regulating element comprising: a

heat transmissive, electrically non-conductive, cylindrical container; a compact column of aligned silicon carbide granules enclosed within said container; and a pair of electrically conductive connectors, each of said connectors extending into a corresponding end of said container and contacting the end of said column adjacent said corresponding end of said container.

4. A voltage regulating element comprising: a heat transmissive, non-conductive, open-ended cylindrical container; a compact column of aligned silicon carbide granules enclosed within said container; an electrically non-conductive cylinder spaced from said first container; a first electrically conductive plug extending into said cylinder and contacting one end of said column, said plug being provided with a shoulder for retaining said plug in fixed relation to said cylinder; a second electrically conductive plug extending into said cylinder and contacting the other end of said column, said second plug being provided with a spring retaining shoulder; and a compressed helical spring arranged in concentric relation with said second plug and disposed intermediate said spring retaining shoulder and that wall of said cylinder through which said second plug extends, said spring applying predetermined pressure to said column via said second plug.

5. Apparatus according to claim 4 characterized in that said cylinder is comprised of two longitudinal sections, in adjustably threaded engagement with each other, whereby the degree of compression of said spring may be varied, thereby adjusting the pressure applied to said column via said second plug.

6. A voltage regulator adapted to maintain the voltage across an electrical load, when in shunt circuit relation therewith, substantially constant under varying conditions of supplied voltage and load current, said regulator comprising: an electrically non-conductive, heat transmissive container, a column of silicon carbide particles longitudinally enclosed by said container, an electricaly conductive plug closing one of the narrow ends of said container and intimately contacting said column, a longitudinally insertable, electrically conductive plug closing the other narrow end of said container and intimately contacting said column, and a compressionally adjustable pressure spring backing said insertable plug, whereby the compressional force exerted on said column by said spring via said insertable plug may be varied.

7. A shunt-type voltage regulator comprised of a compact column of silicon carbide granules, an electrically non-conductive, heat-transmissive container enclosing said column, and a pair of conductive elements penetrating said container and contacting said column, one at each end thereof, said conductive elements being adapted to provide shunt connection of said regulator.

8. Apparatus according to claim 7 characterized in that said silicon carbide granules are arranged and disposed within said container so as to occupy substantially the least volume per unit of weight.

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